Chapter 3

Drive Systems

Drive Systems

Urs Rüesch

1. INTRODUCTION

The power range of the drives in a cement work is very wide-spread. We normally find motors ranging from 0.2 kW up to 6 MW.

Low voltage drives are fed with 380 V to 580 V. For direct feed of drives exceeding 250 kW, the voltage range of 3.6 kV to 6 kV (11 kV) is used (high voltage motors).

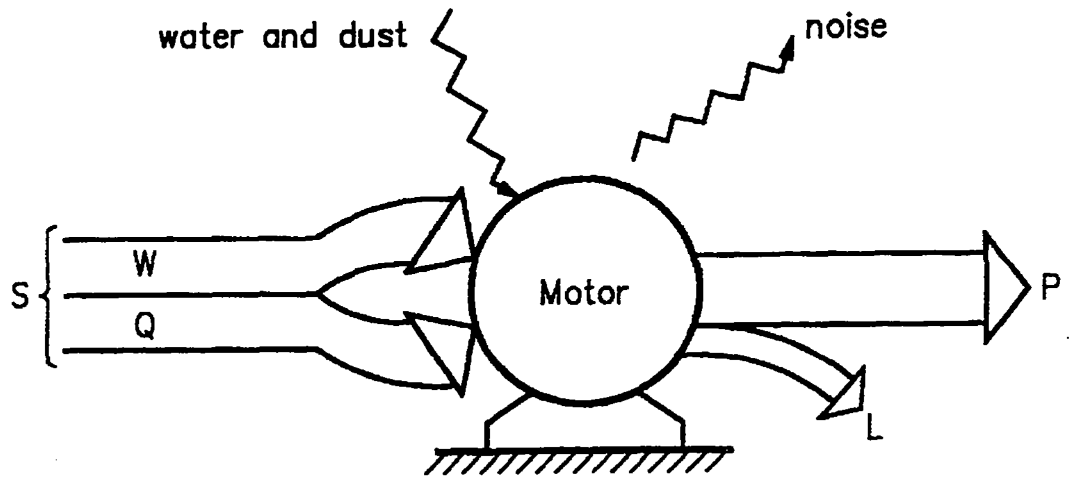
The evaluation criteria of high or low voltage drives are additionally dependent on:

- the distance between the motor and the substation (cable costs)
- investment costs of the drive
  (including costs of switching elements).

There is a certain tendency to raise high voltage to 10 KV and the low voltage to 660 V. With higher voltage, service currents and short-circuit currents are reduced, thus a number of advantages are attained, e.g.:

- smaller cable cross-sections (lower investment costs)
- full advantage can be taken of the 10 kV voltage by the switchgear
- low voltage motors can be used up to 500 kW.

Fig. 1: Input/output diagram



W : active power (kW)
Q : reactive power (kVar)
S : apparent power (kVA)

P : mechanical power (kW, J/s)
L : loss (~heat)

$$S : \sqrt{W^2 + Q^2} \longrightarrow \text{power factor} = \frac{W}{S}$$

$$W = P + L \longrightarrow \text{efficiency} = \frac{P}{W}$$

The size and thus the investment cost of a motor is not only dependent on the power, but also on the speed of the motor:

- power = torque x speed

To understand the operation of a drive it is very important to know the characteristic "torque vs speed".

The influence of the torque or speed on the size of a motor can also be explained by means of a mechanical example:

- truck (30 t payload)
  motor: 15 l > power = 200 kW
- formula 1 racing car
  motor: 2 l > power = 400 kW

The truck motor generates a much higher torque at a much lower speed.

The very high degree of efficiency - up to 96% - of electrical drives should be mentioned. In spite of this high rate, the warming of large motors due to losses is remarkable.

Thus, ventilation should never be neglected in the planning of electrical drives. Depending on the prevailing conditions, machines can be cooled in different ways:

- natural cooling by convection, heat by itself produces an air current
- forced cooling by fans and filters
- forced cooling by air-to-air or air-to-water heat exchanger
  (closed-circuit ventilation).

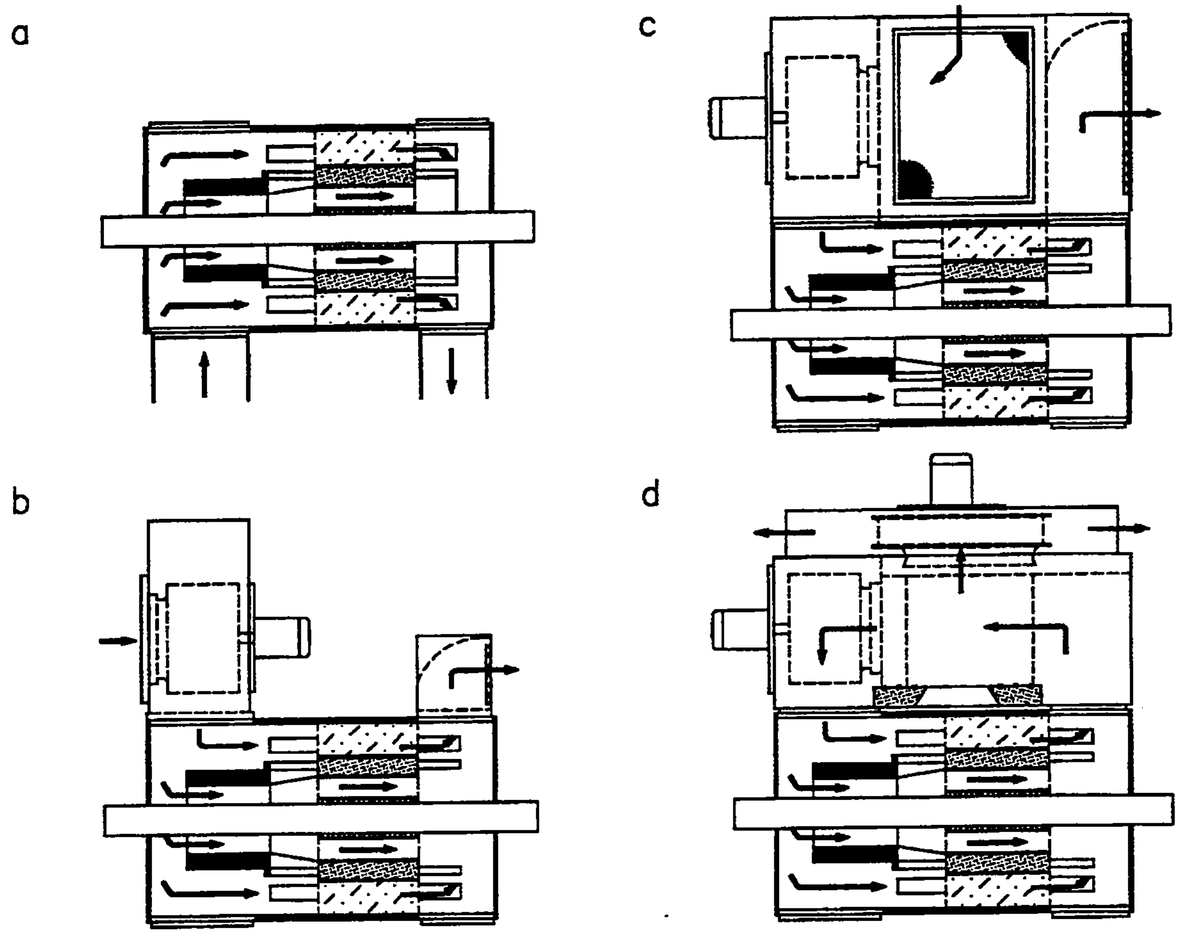
The box-shaped casing makes the motor very versatile as regards its enclosure, so that it can be adapted to suit the wide range of environmental impacts encountered in cement works, most of which are far from favourable. For example, if a motor has to be installed outdoors, it can be fitted with a weather-proofing attachment. If the attachment is also lined with sound-absorbent material, it acts furthermore as an excellent silencer.

The type of protection of a motor is very important in the cement industry. The different types of protection are characterized by the so-called IP (interelement protection) class, followed by two numbers which indicate the degree of protection (according to IEC). e.g. IP 44 means:

- protection against foreign bodies with a diameter above 1 mm
- protection against spray water from all directions.

The cooling of a motor is closely related to its protection. The ideal solution of a completely closed, surface-cooled motor is problematic for big motors. Forced cooling with air filters or air/water heat exchangers are required. Figure 2 shows some examples.

Fig. 2: **Various alternatives for air-cooling and protection (for motors bigger than 1 MW)**



a) separate ventilation, inlet and outlet through ducting
b) machine fitted with fan and exhaust shroud
c) machine fitted with through-draught ventilation unit with built-in filters
d) machine fitted with air-to-air cooling ventilation unit; the internal and external cooling air circuits are completely separate.

2. MOTORS

2.1 Squirrel cage motor (induction motor)

2.1.1 Construction

The squirrel cage motor is in its construction the simplest motor used in the cement industry. The main feature is a rotor without external connections (no slip rings, no brushes). Its two bearings are the only parts exposed to wear and tear. It is furthermore economic in price.

Fig. 3: Typical connection diagram of a squirrel cage motor

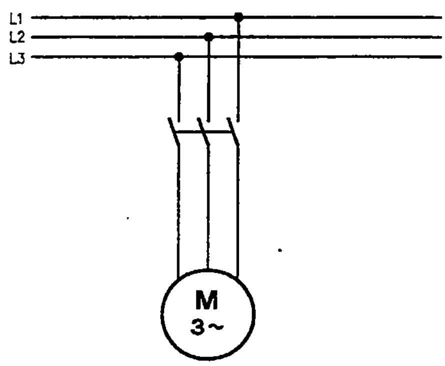
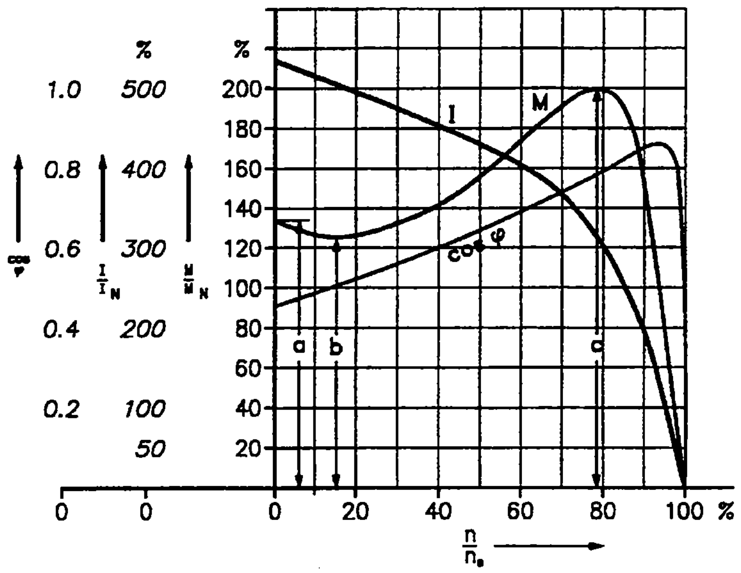


Fig. 4: Typical starting characteristics of a squirrel cage motor



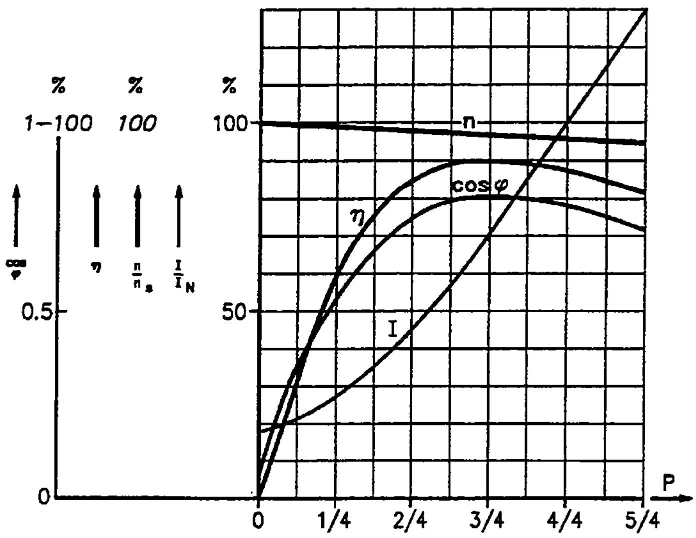
a :	starting torque	b :	saddle torque
c :	break-down torque	I :	current
M :	torque	n :	speed
cosφ :	power factor	η :	efficiency
P :	load		

2.1.2 Operating Characteristics

The squirrel cage motor has a high starting current of 3.5 to 7 times full load at relatively constant speed.

The torque changes with the square of the voltage.

Fig. 5: Operating characteristics of a squirrel cage motor (abbreviations see Figure 4)



2.1.3 Application

For almost any drive with a constant speed requirement and not too long a starting time. From a fraction of a kW to thousands of KW.

2.2 Slip ring motor

2.2.1 Construction

The slip ring motor, like the squirrel cage motor, is an induction motor.

Its rotor windings are brought out to slip rings which allow to control the starting torque and current within a wide range.

Fig. 6: Typical connection diagram of a slip ring motor

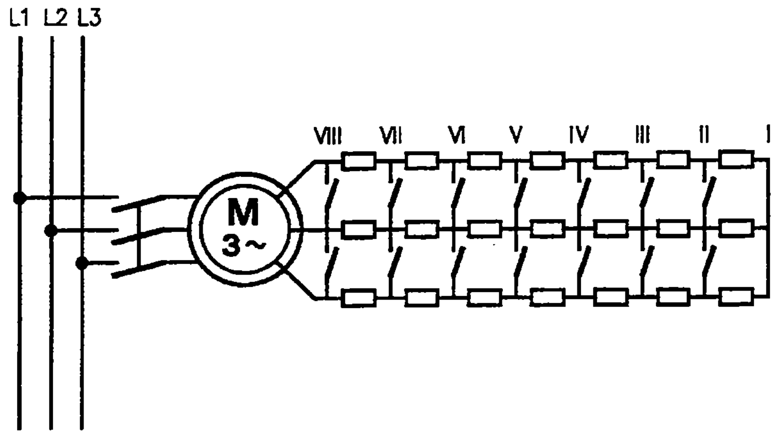
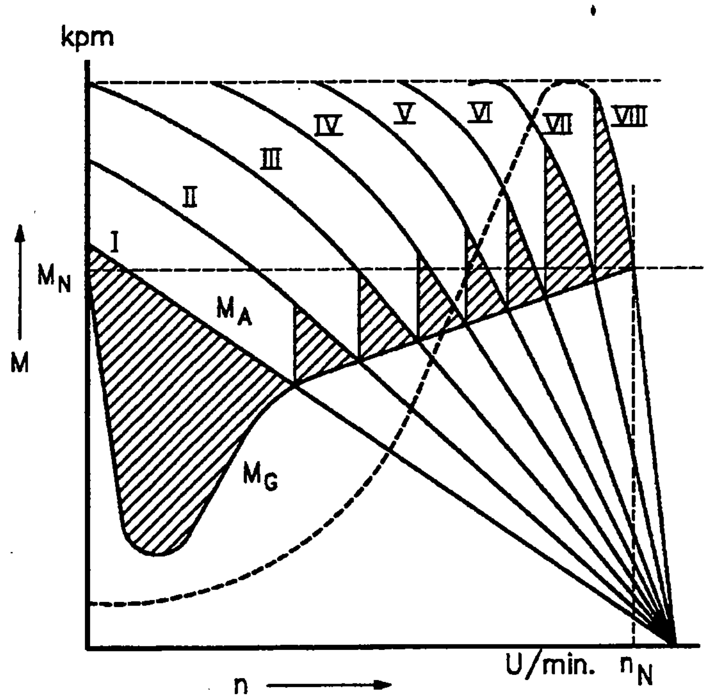


Fig. 7: Start of a slip ring motor by eight steps



M_N : nominal torque

M_A : torque characteristics during start-up

M_G : torque of the load

The introduction of an external resistance in the rotor circuit changes the torque characteristic of the motor and reduces the starting current. It allows changes of the torque of the motor and adaptation to the torque of the load (e.g. maximum torque at standstill).

The starting time of the motor can be extended since most of the heat is generated in the starting resistor away from the motor.

Metal starting resistors are built in different numbers of steps as required by the drive.

The last step of the resistor may be permanently connected to the rotor when the drive requires a softer torque characteristic.

Liquid starting resistors provide smooth and continuous acceleration.

2.2.2 Operating Characteristics

The slip ring motor is, once started and short-circuited with the resistor, not different from the squirrel cage motor.

2.2.3 Application

Where the starting torque and the starting current must be adjusted to the specific requirements of the drive. From one to thousands of kW.

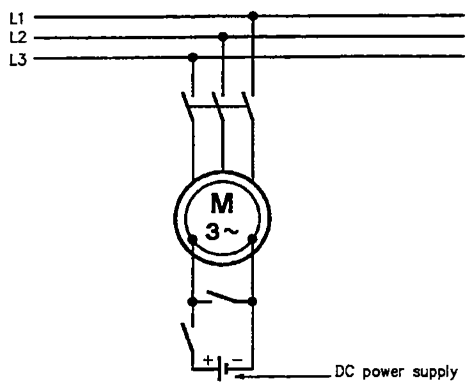
2.3 Synchronous motor

2.3.1 Construction

The synchronous motor has a rotor with salient poles. The rotor is connected by slip rings and brushes to a direct current power supply for its excitation.

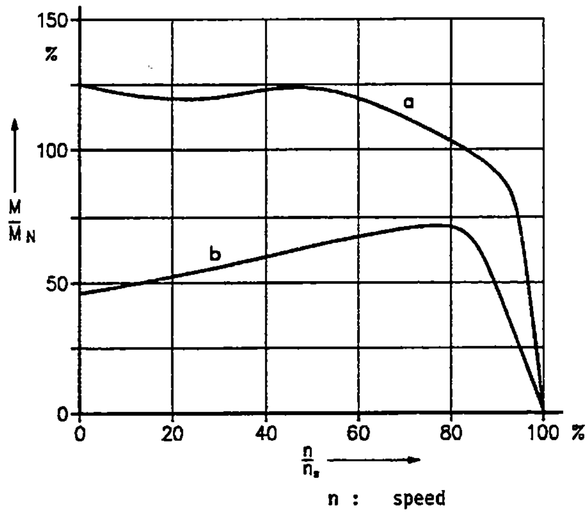
The AC windings are in the stator. The starting torque of an ideal synchronous motor is zero. To improve this situation, the rotors of synchronous motors are normally equipped with a squirrel cage type winding.

Fig. 8: Typical connection diagram of a synchronous motor



2.3.2 Starting Characteristics

Fig. 9: Typical starting characteristics of a synchronous motor



M : torque

a) Motor with massive poles and starting winding

b) Motor with laminated poles and starting winding

The synchronous motor accelerates, similar to a squirrel cage motor, up to near-synchronous speed. At his point the so far short-circuited DC winding is connected to the rotor. The torque now produced will accelerate the motor to synchronous speed.

2.3.3 Operating Characteristics

The speed of the synchronous motor is proportional with the frequency of the supplying network and independent of the load on the motor shaft up to the break-down torque. The break-down torque is 1.5 to 1.9 times the nominal torque and depends on the excitation.

The great advantage of the synchronous motor is its capability of compensating reactive power and the very high efficiency of 96 to 98%.

2.3.4 Application

For rather steady loads with no speed control above 500 kW and where reactive power has to be compensated.

2.4 Synchronous induction motor

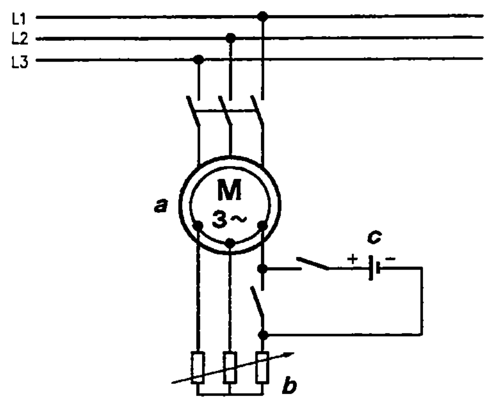
The synchronous induction motor combines the advantages of the slip ring motor and the synchronous motor.

It has the high starting torque at a low starting current of the slip ring motor and also the capability of compensating reactive power.

2.4.1 Construction

The synchronous induction motor is built like a slip ring motor; only the mode of operation differs.

Fig. 10: Typical connection diagram of a synchronous induction motor



a) induction motor

b) starting resistor

c) DC power supply

2.4.2 Starting Characteristics

The synchronous induction motor starts with a starting resistor like a slip ring motor. After the starter has short-circuited the rotor windings, the DC field is applied and the motor accelerates to full synchronous speed.

2.4.3 Operating Characteristics

In the synchronized operating mode the motor acts like a synchronous motor. It can operate with unity power factor or even compensate reactive power.

2.4.4 Application

For rather steady loads with no speed regulation, above 500 kW. Where reactive power has to be compensated and starting torque and current have to be adjusted to the requirements of the drive.

2.5 DC motor (direct current motor)

Its name implies that the DC motor runs on a direct current power supply.

This power supply is not directly available in our cement plant. To connect a DC motor to our three-phase alternating current network, an AC-DC converter is required (see para 3. below).

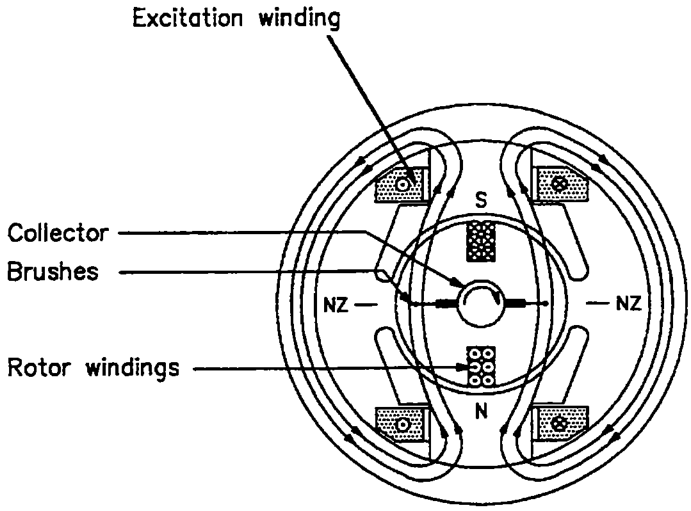
2.5.1 DC Motor Design

Like all other electric machines, the DC motor consists of a stator and a rotor.

The excitation windings around the main stator poles are fed by a DC power supply and produce a constant magnetic field.

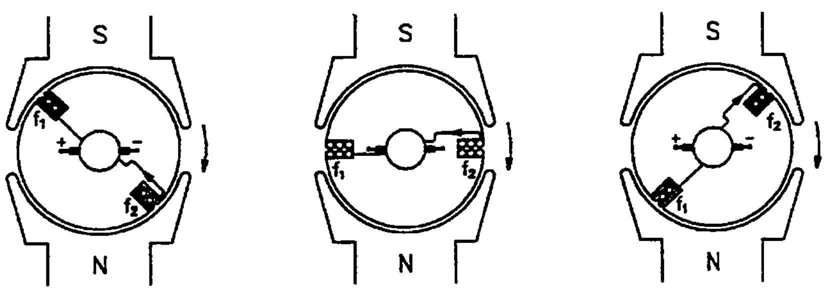
The DC current in the rotor conductors underneath the main poles produce a tangential force on the rotor which is identical to the torque on the motor shaft.

Fig. 11: Magnet flux of a DC motor



N: north pole S: south pole NZ: neutral zone

Fig. 12: Magnetic forces turning the rotor



The rotor now moves to the neutral position between the south and the north pole.

To keep the armature rotating, a polarity change in the rotor circuit is required. This is achieved with the collector.

Commutation poles are furthermore installed in the neutral zones between north and south pole. These compensate the remaining magnetic field and thereby improve the commutation.

Fig. 13: DC machine with main and commutation poles

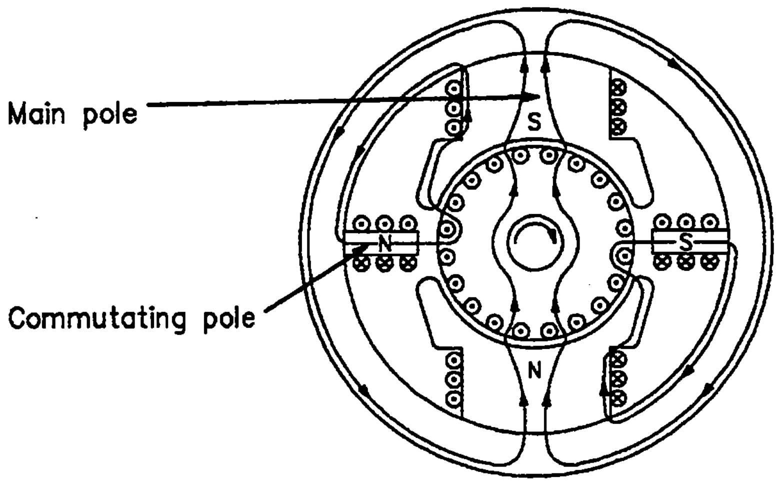
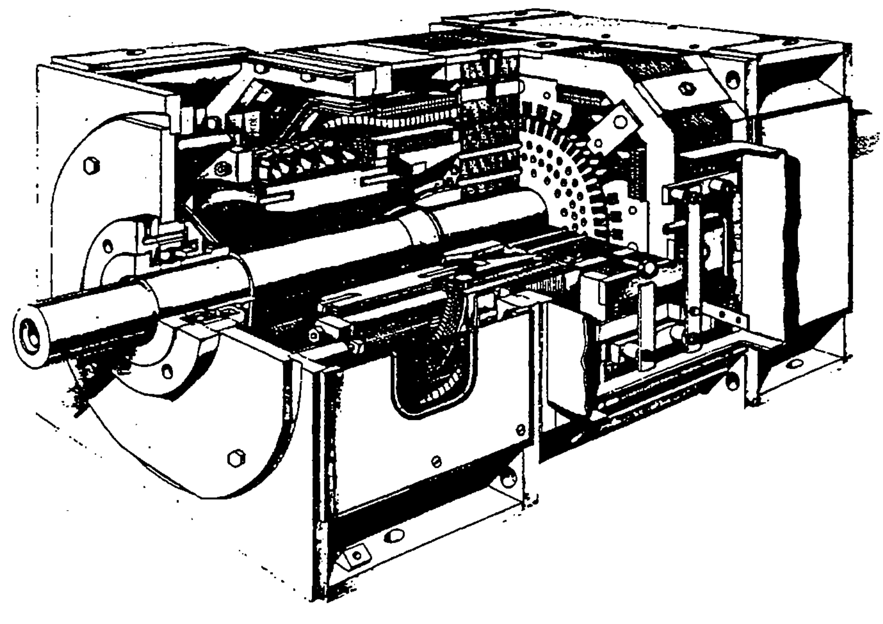


Fig. 14: Cut-away view of a large DC motor



2.5.2 Characteristics of a DC Motor

The DC motor offers the great advantage of a simple torque and speed control over the full speed range, as well as high efficiency also for low speeds.

The torque can either be constant over the whole speed range, or any particular speed can be maintained independent of the torque.

These properties made the DC motor the most commonly used variable speed drive in the cement industry.

The main drawbacks of the DC drives are that they:

- are 2 - 4 times more expensive than squirrel cage motors
- are maintenance-intensive (collector, power electronic)
- are space-intensive (transformer, converter)
- require many spare parts

2.5.3 Application

DC motors are installed where variable speed is necessary and where the excellent characteristics of the drives outweigh the above mentioned drawbacks. Crusher feeders, weigh belt feeders, separators, kiln drives and kiln fans are such possible applications.

2.6 Ring motor (gearless mill drive)

2.6.1 Construction

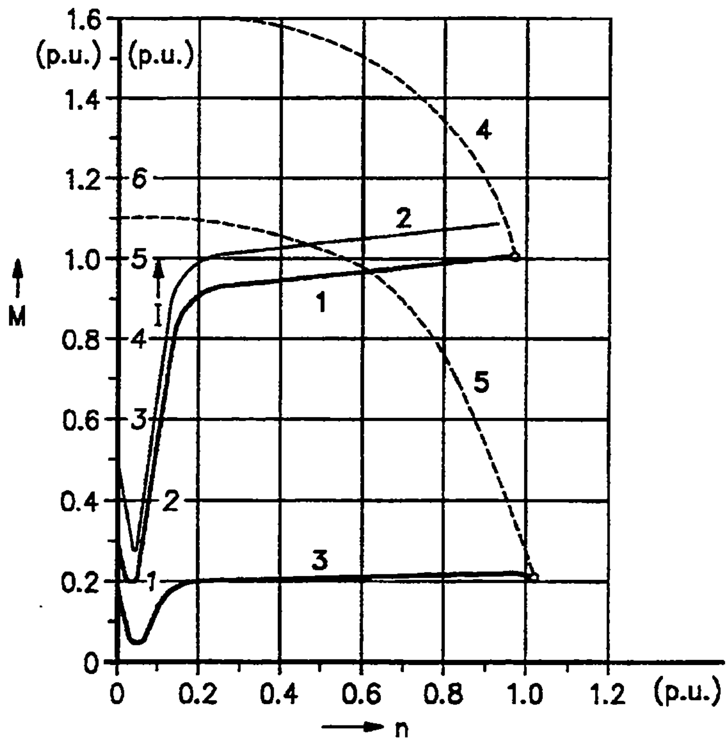
The ring motor is a synchronous motor. However, the stator has a variable frequency supply, generated in a frequency converter as described in para 3. below. The frequency ranges between zero and a few Hertz.

2.6.2 Operating Characteristics

The feature of variable frequency is used to start the motor. The torque can then be adjusted to the torque of the load resulting in a very smooth starting with low starting currents.

The power factor of the motor itself can be unity, the frequency converter, however, requires some reactive power.

Fig. 15: Starting characteristics of a synchronous motor with frequency and with asynchronous starting



M) torque

n) speed

I) motor current

1) torque of the load (mill)

2) torque with frequency starting

3) current with frequency starting

4) torque with asynchronous starting

5) current with asynchronous starting

3. POWER ELECTRONICS

3.1 Introduction

The recent development of semiconductors has raised the application of power electronics to a level of considerable importance. The capacity/price ratio has become very interesting, and the reliability of the elements is in accordance with the industrial specifications.

To distinguish between electronics and power electronics, it may be said that electronics handle currents above 1 mA while power electronics handle currents above 1 A. The present maximum is about 9000 A (rectifier diodes) for a single element.

The principle elements of power electronics are:

- diodes
- transistors
- thyristors
- triacs
- GTO (gate turn-off thyristors)
- IGBT (insulated gate bipolar transistors)

Other electrical switching elements, such as the conventional thyratron, are not a subject of this exposé as they are vacuum-tube based and very rarely applied in the cement industry today; but functionally, these multi-grid tube elements possess similar operating characteristics.

The above mentioned electronic switches can be compared with other physical media, e.g. valves in water mains.

3.2 Operating characteristics of power electronic elements

3.2.1 Diode

The symbol for a diode is shown in Figure 16 below. The operating characteristics of this element are very easy to understand. If a voltage "U_1" is applied across the diode from anode A to cathode C, the a current "i" will flow through the diode. If the voltage "U_2" is reversed from C to A, the diode blocks the current, i.e. no current will flow.

Figure 17 demonstrates the "rectifying effect" of a diode.

Fig. 16: Symbol for a diode

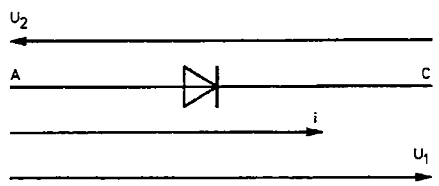
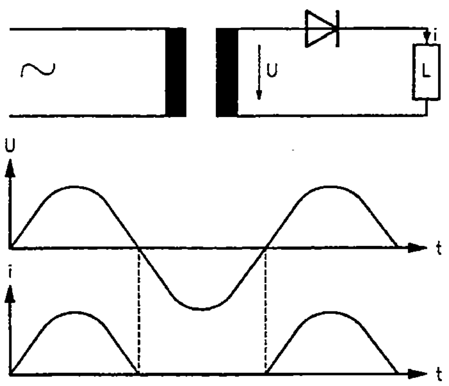


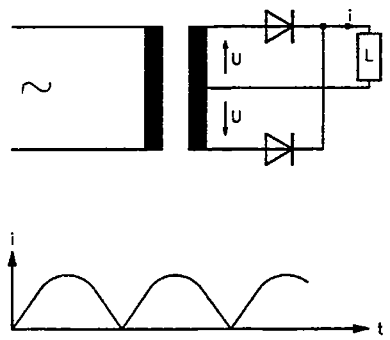
Fig. 17: "Rectifying effect" of a diode (half-ware rectifier)



The voltage "U" changes its polarity with every cycle. When the voltage across the diode is "positive" a current "i" flows through the load "L".

Figure 18 below shows a more efficient network.

Fig. 18: Full-wave rectifier



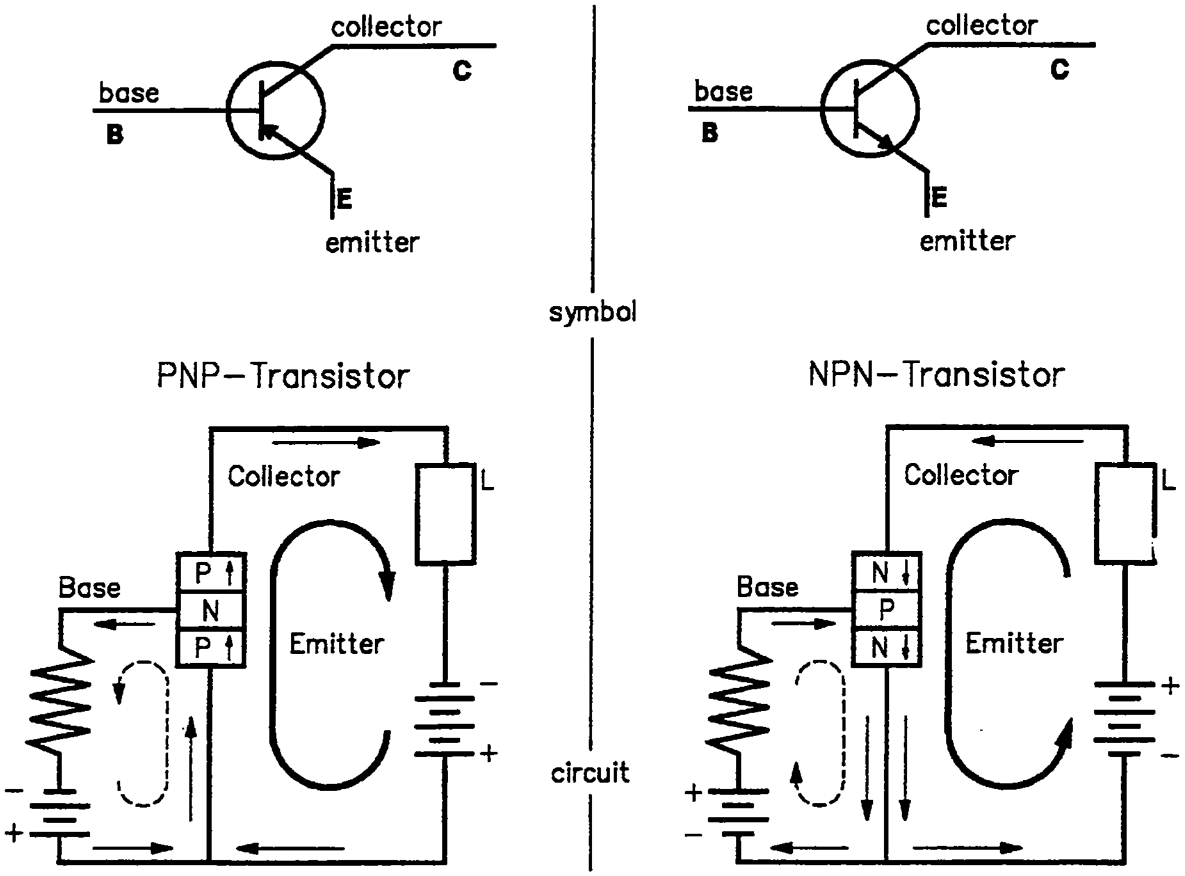
The current "i" is conducted alternatively by the two diodes. The time phase when the one "passes" the current to the other is called commutation.

3.2.2 Transistor

The transistor is built with three semi-conducting materials similar to a diode, which has two. Depending on the physical arrangement of these three semi-conducting materials, the literature speaks of PNP or NPN transistors. Also, the symbol and electrical circuitry is different, but today generally the PNP concept is manufactured.

The transistor can be used in many different circuit-configurations, but is basically a current amplifier, whereas the old electron tubes where voltage amplifiers.

Fig. 19: Symbols and typical transistor circuits



- ➠ small current controlling the transistor (closed or conducting)
- ➠ large current through the load

(note: arrows do not indicate the electron-flow)

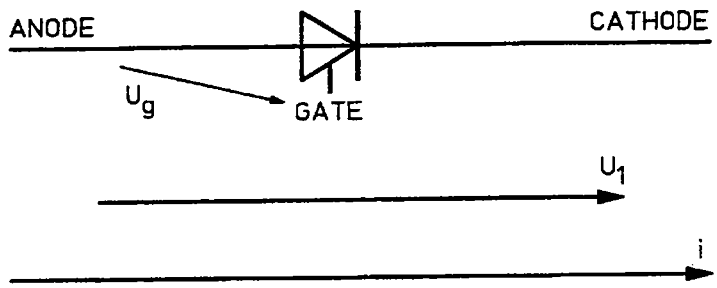
The transistor input current (base-emitter) controls the transistor output current (emitter-collector) in a proportional manner over a certain range. Of course, the same transistor may also be used as switching element only, i.e. fully closed and fully conducting. Above is identically valid for PNP and NPN types.

Elements with output currents above 1 A are called power transistors, used as last stage in amplifiers and variable frequency converters for smaller drives up to approx. 400 kW.

3.2.3 Thyristor, Triac

The symbol for a thyristor is shown in Figure 20. The operating characteristics of this element are similar to those of a diode except for the additional ignition voltage "U_g" from point anode A to point gate G.

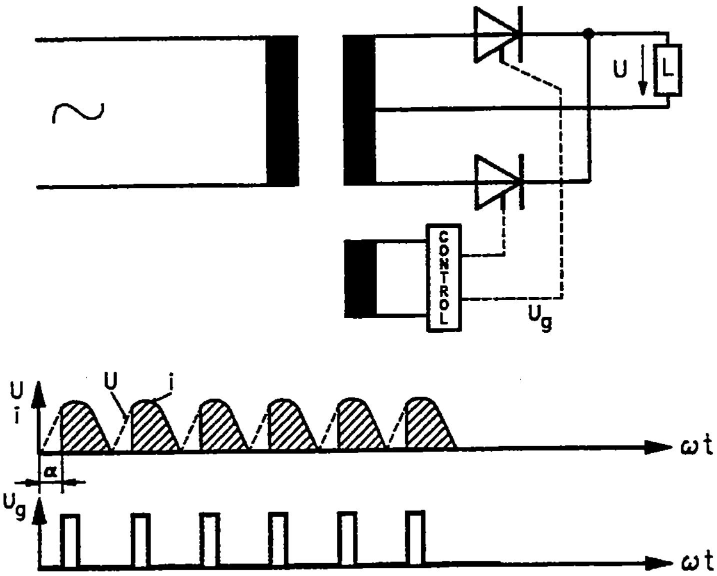
Fig. 20: Thyristor symbol



If a voltage "U_1" is applied across the thyristor, current "i" will only flow through the element when a voltage "U_g" (ignition voltage) is applied between A and G. The current "i" will flow only as long as the voltage "U_1" does not change its polarity.

The network in Figure 21 demonstrates the use of thyristors as a voltage regulator for DC.

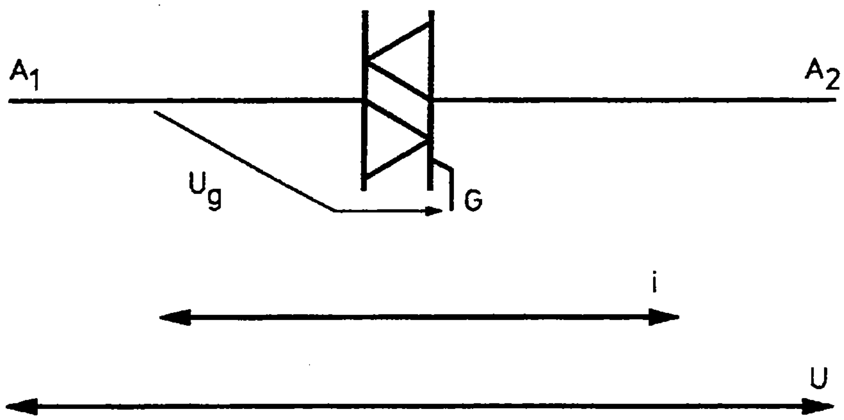
Fig. 21: Network for a variable DC supply



By altering the angle of ignition, α, one can alter their voltage "U" across the load "L", theoretically within the range 0 - 100%.

The symbol for a triac is shown in Figure 22 below. A triac consists of two antiparallel thyristors. This element represents an electronic switch for alternating current.

Fig. 22: Symbol for a triac.



A_1 = anode 1

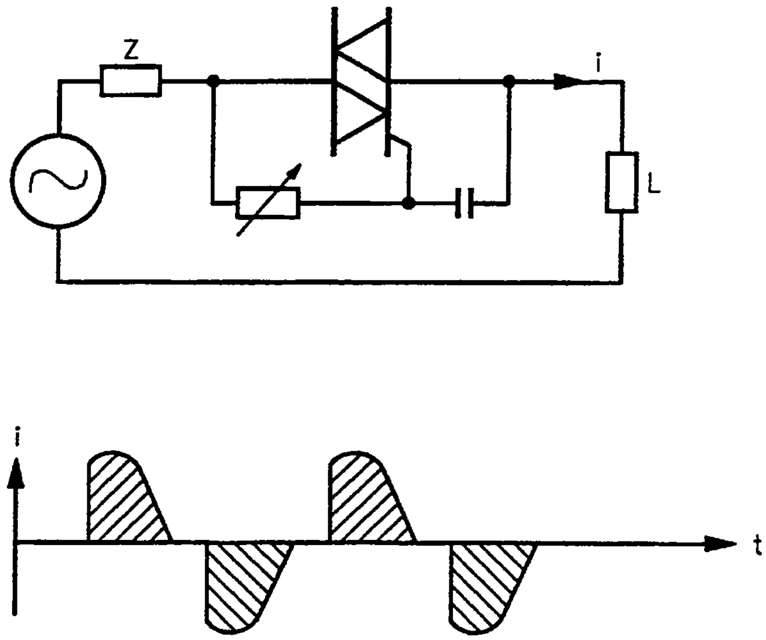
A_2 = anode 2

U_g = ignition voltage

Together with the ignition voltage "U_g", the triac is able to conduct the current in both directions.

Figure 23 below shows its application as a "voltage" regulator" for an AC-load.

Fig. 23: The triac as "voltage regulator" for an AC-load



3.2.4 GTO (Gate turn-off-thyristor)

The symbol for a GTO is shown in Figure 24 below. The special feature of the GTO's is that they are not only turned on through their gate, but also off. Naturally, this would be the ideal switch, because no forced commutation equipment would then be needed to turn off the current when the thyristor is operated on direct voltage. In order to turn off the thyristor through the gate, negative triggering pulses which are large enough to reduce the load current of the thyristor below the holding current for a brief time are required. The turn-off pulse must be at least 10% of the forward current.

Fig. 24: Symbol for a GTO

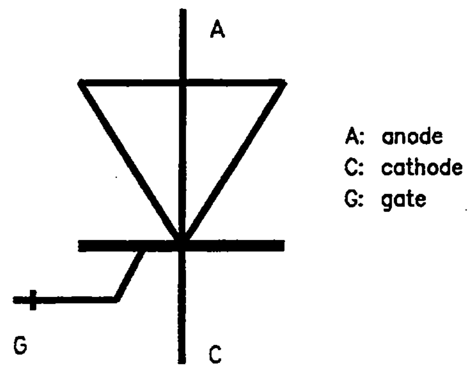
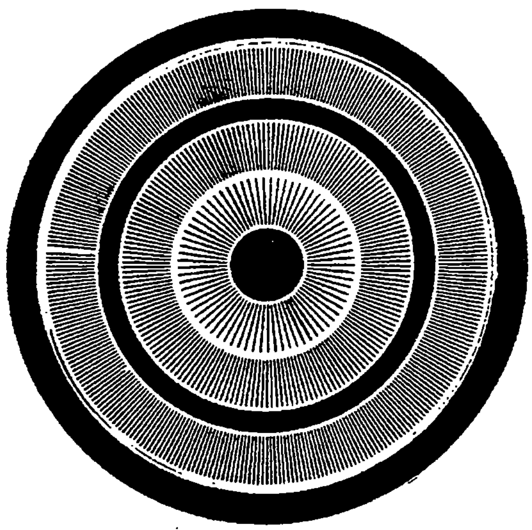


Figure 25 shows a pill of silicon with multitude of small, circular arranged "cathode-fingers" which are looking out of a connected gate-surface. Each "finger" is an independent small GTO. All these small GTO's are connected in parallel to a large GTO.

Fig. 25: Pill of silicon



Gate turn-off thyristors are used for forced-commutated current converters and static inverters.

3.2.5 IGBT (Insulated gate bipolar transistor)

The IGBT is a combination of the advantageous characteristics of a bipolar transistor and a self-blocking field effect transistor (MOSFET). Its characteristics are a powerless drive like a MOSFET, a low forward resistance and a high inverse voltage like a bipolar transistor. Figure 26 shows the equivalent network and figure 27 the symbol for an IGBT.

Fig. 26: Equivalent network for an IGBT

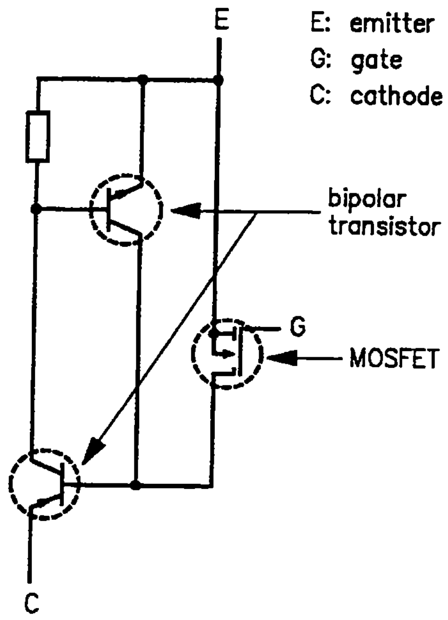
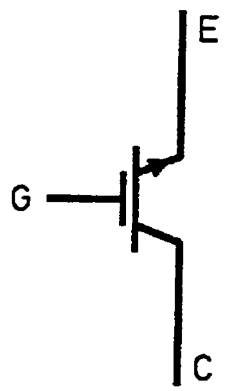


Fig. 27: Symbol for an IGBT



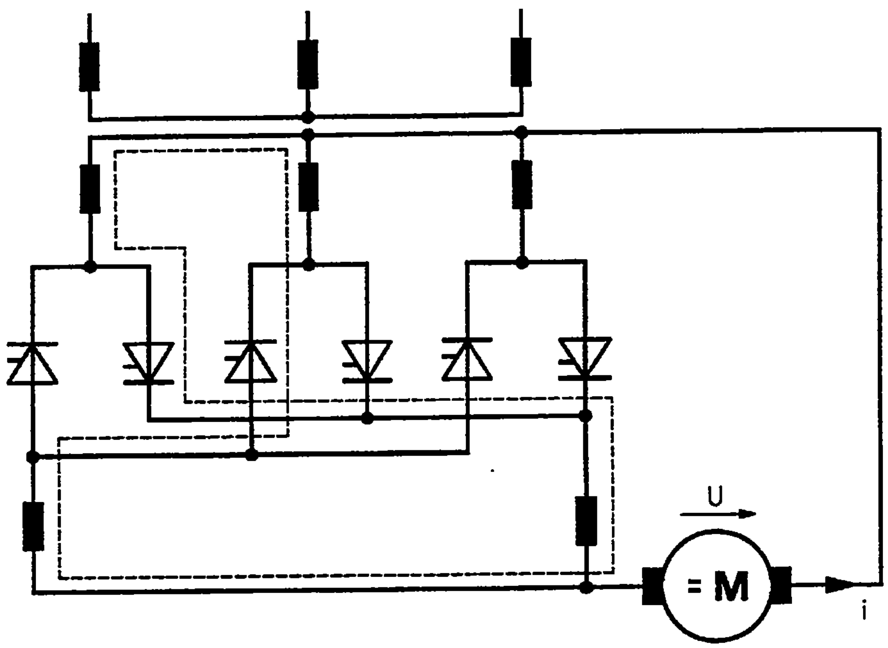
The IGBT is suitable for numerous applications in power electronics, especially in pulse width modulated servo and three-phase drives requiring high dynamic range control and low noise. They also can be used for power-supplies and other power circuits requiring high switch repetition rates.

IGBT's will replace the bipolar darlington-transistor in many applications because the control circuit is less sophisticated and thus cost-efficient.

3.2.6 Application for power electronic elements

Figures 28, 29 and 30 illustrate how a frequency converter can be built with the aid of power electronic components.

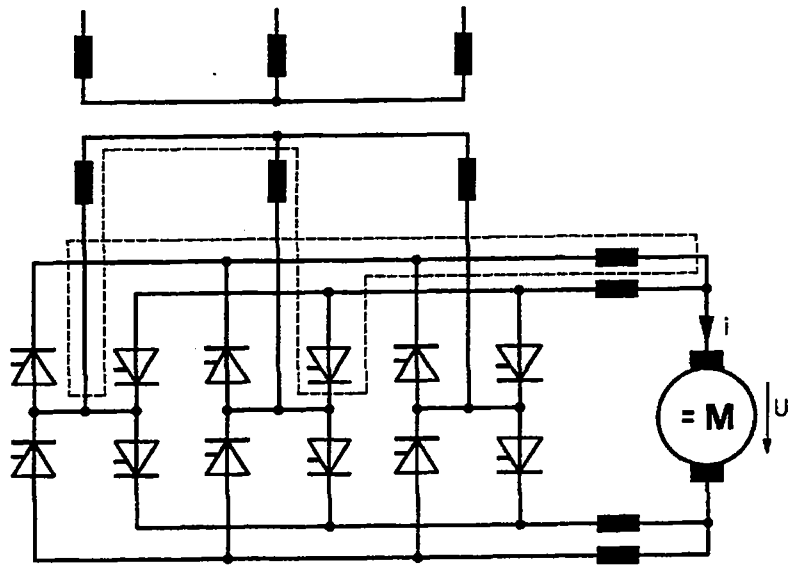
Fig. 28: 3-pulse anti-parallel circuit



— load current

----- circulating current (during transfer motoring to regenerating)

Fig. 29: 6-pulse anti-parallel circuit

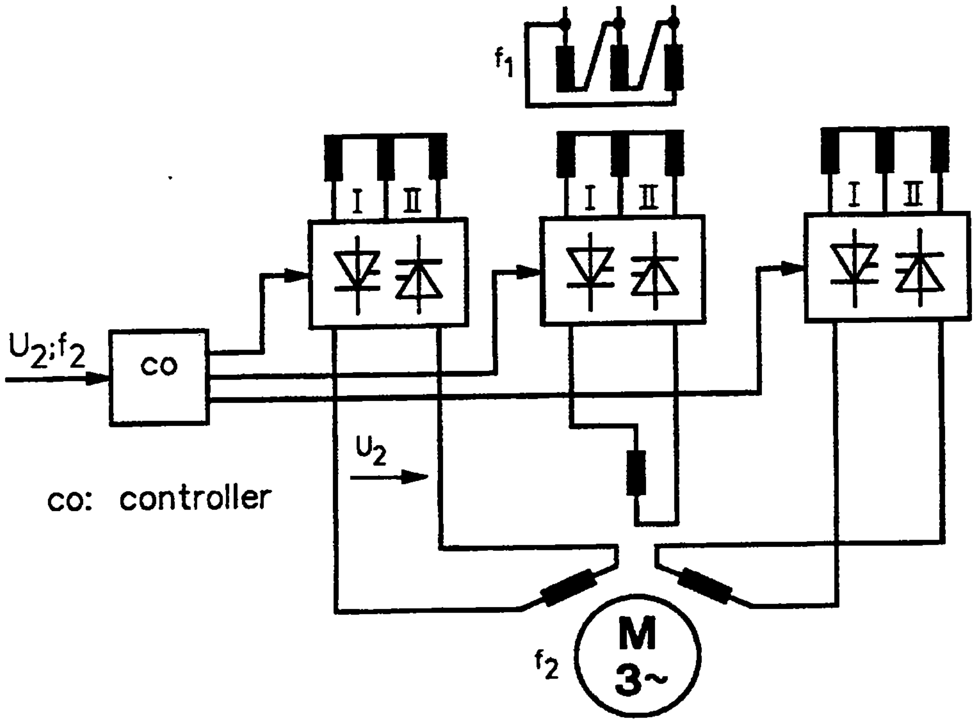


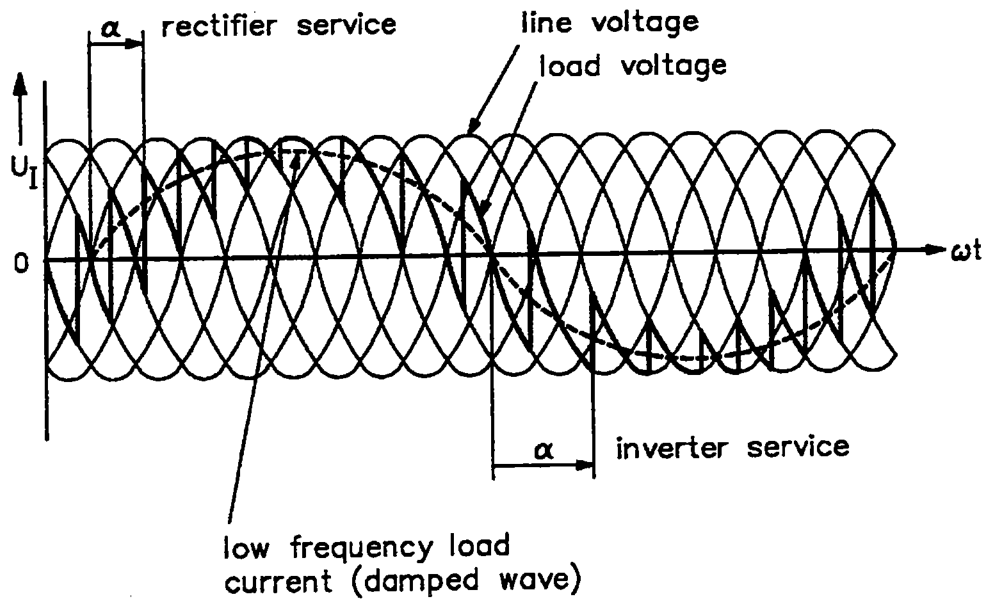
— load current

----- circulating current (during transfer motoring to regenerating)

Figure 30 shows a mounting diagram and voltage from an output phase of a frequency converter. Each output phase is formed by a 6-pulse anti-parallel partial-current converter. Totally at least, 3x2-6 (3-phase; 2-anti-parallel; 6-pulse) = 36 current converters are needed. The two partial-current converters change between rectifier - and inverter service; so that the output-voltage will be sine shaped.

Fig. 30: Example for a frequency conversion with a time-dependent ignition control





3.3 Application for power electronics in the cement industry

In modern cement works power electronics are used as:

(a) rectifiers for
- electrostatic filters
- magnetic separators
- DC power sources

(b) voltage regulators for
- speed (torque) control of DC drives
- voltage control of electrostatic filters
- electronic contactors

(c) frequency converters for
- speed control of synchronous motors, e.g. ring motor, squirrel cage motors
- stabilized power sources for supply of control equipment, e.g. computers

3.3.1 Advantages of electronic elements

Electronic elements do not wear out. Their modular design permits quick trouble-shooting and short repair times. Furthermore, they offer ideal characteristics for motor controlling, e.g. speed variation.

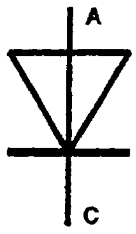
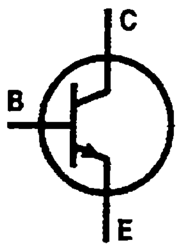
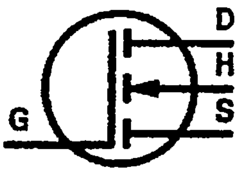
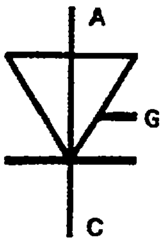
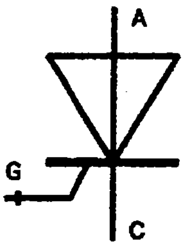
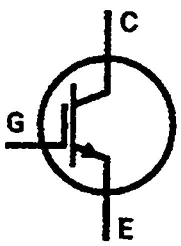
3.3.2 Disadvantages of electronic elements

a) Cooling
Energy losses occur in electronic elements as they are not ideal switches. These losses produce heat and since the switching components have small dimensions, cooling is a considerable problem. The cooling media is usually air, but water may also be used (e.g. water-cooled thyristors of the ring motor at Rekingen). The ambient temperature of electronic boards is often specified up to a maximum of 45°C, thus in most cases air-conditioned rooms are necessary.

b) Distortion of the sine wave form
The above diagrams (e.g. Fig. 30) show that the power electronics "cut" the source sine-wave in such a way that "angles" are formed. The degree of distortion of the initial wave form represents a quantity of reactive power of higher frequency produced by the power electronics (harmonics).
This high frequency power causes the following inconveniences:

- emission of strong magnetic fields which can disturb control signals (control cables must be protected and separated)
- malfunction of other electrical equipment inside and outside the plant due to distortion of the voltage wave form.

Summary of semiconductor elements for power electronics

Symbole	Description	max. voltage & current
	**DIODES** Diodes ore semi-conductor devices which allow current to flow in one preferred direction. If o positive voltage is applied, the diode operates in the forward direction; when the voltage is negative, it blocks. The properties of a good diode are high reverse resistance, low forward resistance and high allowable temperature. Standard and avalanche diodes are used mainly for rectification in circuits operating ot mains frequency Fost recovery diodes ore used for static frequency changers or in pulsed power supply units.	Revers voltage: 100 V ... 30 kV max. permissible RMS on-state current: 1A ...9000 A
	**POWER-TRANSISTOR** (Power field effect tranistor) The silicon pellet of the bipolar power transistor consists of three layers of alternate p and n type silicon material with two pen ¡unctions. On principle the succession of the layers npn or pnp is possible but today only the pnp concept is manufactured to achieve optimum electrical characteristics for power electronics. Power transistors are almost exclusively fumed on and off in "Switching operation". To allow the output current to flow, a forward base current must be maintained for the desired duration of the conducting state. When removing the control signal the power transistor reverts to the blocking state.	max. collector - emitter voltage: 100 V ... 1400 V max. DC collector current: 20 A... 400 A
	**POWER-MOSFET** The Power-MOSFET is a controllable switch, if it is running in forward directions. In this case the MOSFET can block up high invers voltage and can switch high power. In backward running it has similar qualities like a diode, but it is possible to influence the characteristic curve with the tension on the gate. The MOSFET has on advantage over the bipolar transistor because no control current is necessary. The Power-MOSFET are used for rectifier for DC-motors, frequency converter for AC-motors and power supply units.	Break-through voltage 50 V... 1000 V Output current: 2 A... 100 A
	**THYRISTOR** The silicon pellet of the thyristor consists of four or more foyers of alternate p and n type materials. It has two different conditions, one is high-resistance and the other one is law-resistance. The difference between a diode and a thyristor is, that a thyristor can switch between the two conditions with a current at the gate. To switch off the current, the thyristor needs a quenching capacitor. Thyristors ore used for contactless switches and controlled rectifiers.	Reverse voltage: 100 V... 5000 V max. permissible RMS on-state current: 10 A ... 5500 A
	**GTO** (Gate turn-off Thyristor) The special feature of the GTO is that they are not only turned on through their gate, but also off. Naturally, this would be the ideal switch, because no forced commutation equipment would then be needed to turn off the current when the thyristor is operated on direct voltage. The turn-off pulse has to be about 10% of the forward current. Gate turn-off thyristors are used for current converters and static inverters.	Reverse voltage: 100 V ... 4500 V max. current: 10 A ... 3000 A
	**IGBT** (Insulated Gate Bipolar Transistor) The IGBT is o technologically combined device having the advantageous characteristics of a bipolar power transistor and a self-blocking field effect transistor. This characteristic is therefore similar to the MOSFET in the input and to the bipolar power transistor in the output. The IGBT is suitable for numerous applications in power electronics, especially in Pulse Width Modulated frequency converters and three-phase drives.	max. collector - emitter voltage: 100 V ... 1200 V max. DC collector current: 15 A ... 400 A

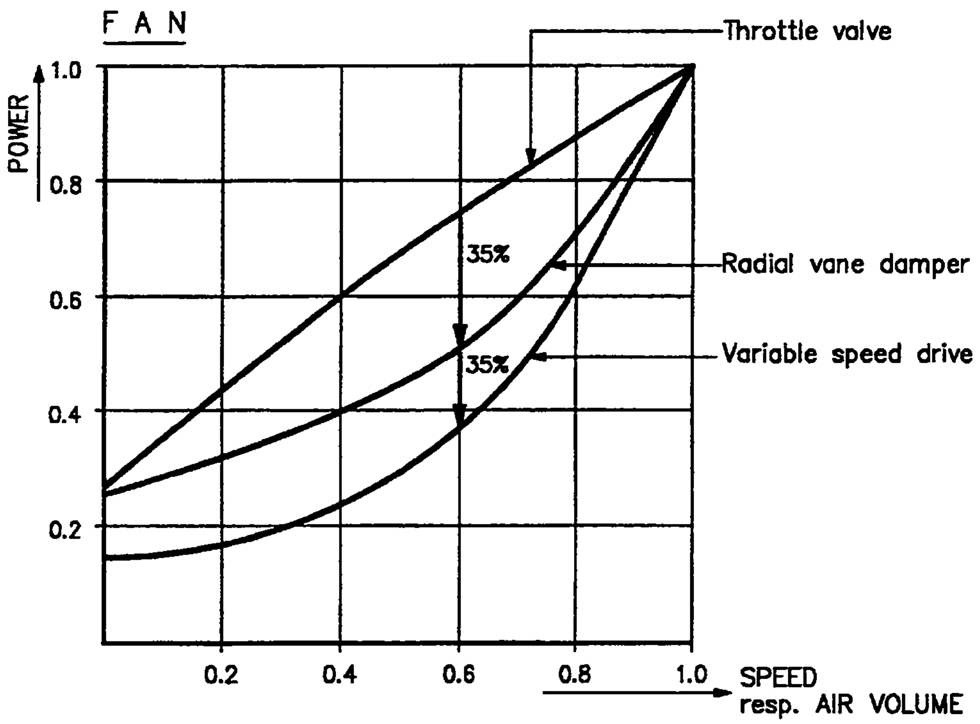
4. VARIABLE SPEED DRIVE SYSTEM

4.1 Introduction

The correct air volume for the process is often achieved by damper control or radial vanes in conjunction with constant speed drives. Considering the "BCM" (Better Cost Management) concept, constant speed and damper control for large fans (1-4 MW) is forbidden today.

Figure 31 compares the reduced energy consumption of using variable speed equipment for fans and pumps with radial vane damper and throttle valve. Where air or water quantities have to be adjusted according to process parameters, a variable flow is needed. Very often, this variable flow is created with more losses than necessary. Compared with other means of flow-adjusting devices, the variable speed drive can save a considerable amount of energy, especially at 50 to 90% of the rated speed.

Fig. 31: Power requirement at different speed



Traditionally, requirements for variable speed in the cement industry were covered with the application of direct current (DC) drives or occasionally by hydraulic drive systems.

As a result of new semiconductor developments in the field of power electronics, many static converter circuits have become reality in recent years. In addition to the traditional DC drive, these static converters have opened up new applications for variable-speed AC drives of high ratings.

This paper presents a number of systems, showing where they can be applied and quoting the criteria which simplify a choice from the wide variety offered.

Some outstanding advantages of a variable-speed drive as follows:

a) Optimal process control

b) Reduced stress on machines and supply system during starting

c) Better utilization of the primary energy owing to the higher efficiency

Familiarity with the entire spectrum of electrical and mechanical variable speed drive systems is not only useful when ordering a new plant, but is equally necessary when carrying out partial modernizations or conversions, e.g. replacing an installation involving undue maintenance or with a poor efficiency.

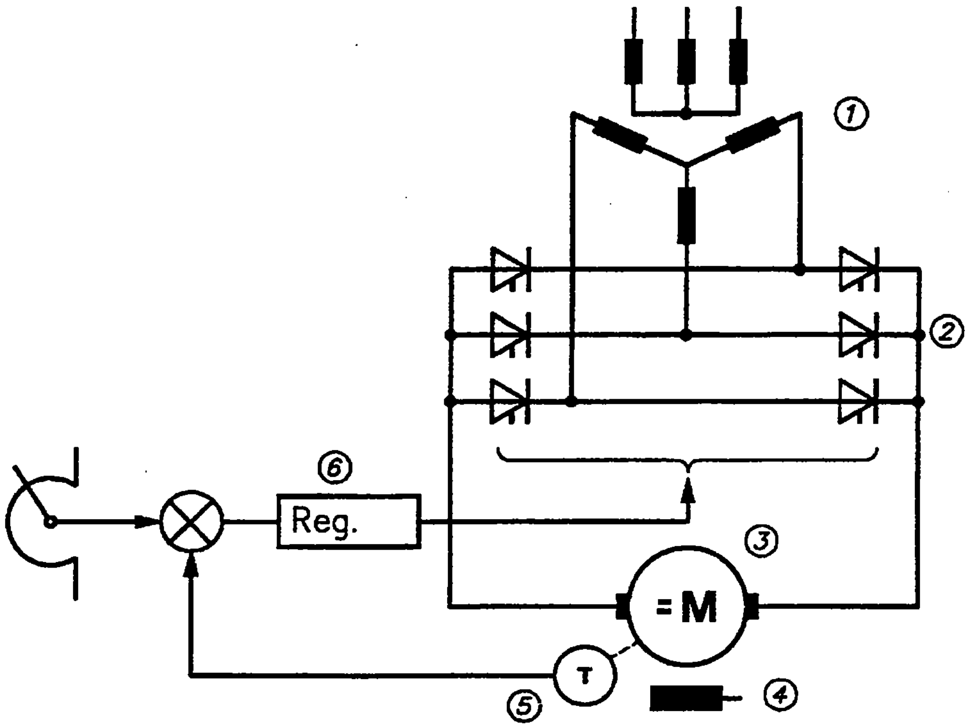
The following catchwords applies for drive specification:

Robust	The drive system must be designed to cope with the typical cement plant environment and the type and quantity of dust prevailing at the location of installation, e.g. clinker dust for cooler fan drives.
Ease of maintenance	The necessary amount of man-hours required by the equipment must be minimal. Diagnostic systems must help to identify failures and indicate steps to correct the fault/failure. Modular design and access must allow for a fast replacement of the defective component in order to restore normal operation.
Reliability	High reliability shall be achieved with adequate sizing of a well-proven drive system. The system shall not be overengineered with additional redundant equipment, which increases the initial installation cost.
Efficiency	Total drive system efficiency is of utmost importance, since it will substantially influence the operating cost for many years to come at an always increasing cost of electrical energy
Investment cost	Last but not least, also the investment cost shall be considered. However, an evaluation oft the investment cost is only meaningful if complete systems are compared including auxiliary installations (e.g. differences in cooling systems, civil works etc.) as well as the operating cost over the next ten to fifteen years.

4.2 Electrical variable speed drive system

4.2.1 DC drive

Fig. 32: DC drive system



A DC drive system normally includes:

- 3-phase isolation transformer (1)
- 3-phase full wave rectifier (2)
- DC motor (3) with shuntfield (4) and tachometer (5)
- electronic speed regulator (6)

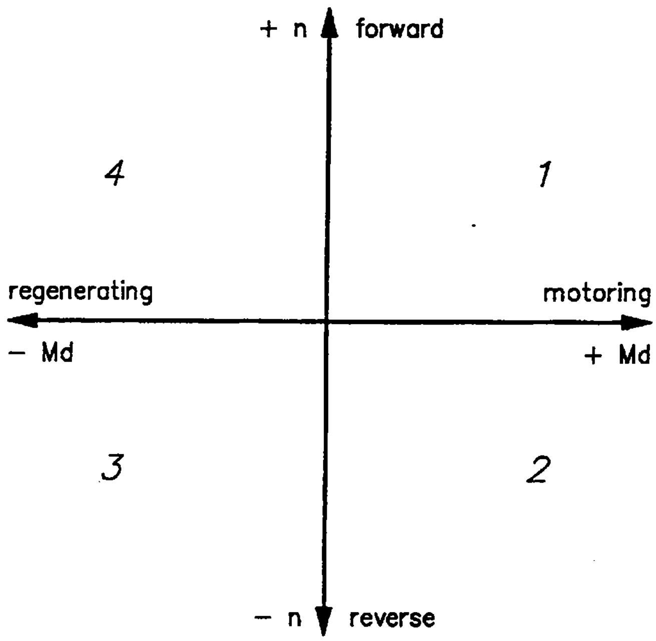
The speed of the DC machine varies proportionally to the applied armature voltage. Motor field weakening can increase the speed even more, but the result is reduced torque. DC drives can be built from less than 1 kW to approx. 1000 kW, considering motor speeds of 3000 min^{-1} for the smaller type and 700 min^{-1} for the larger sizes. At steel mills, large DC drive systems are built up to 8 MW with approx. 100 min^{-1}. The motor size is the limiting factor due to the centrifugal forces of the commutator. The usable speed range is almost infinite, since the DC drive can start and run close to zero speed even under severe overload conditions. Due to the wide speed range, DC drives in most cases require external forced-cooling systems.

4.2.1.1 Operating Characteristics

The scheme as shown in Figure 33 can operate only in quadrant 1, i.e. motoring in forward direction. For full 4-quadrant operation, a double anti-parallel (back-to-back) thyristor bridge arrangement is necessary.

Once the DC motor is equipped with a forced-cooling system, no torque limitations exist. Totally closed DC machines are available too, but they are oversized and cover a limited speed range only. Therefore, a totally enclosed fan-cooled machine is usually very uneconomical. The field weakening range is not used in the cement industry, since it serves mostly for winder applications.

Fig. 33: 4-quadrant operation



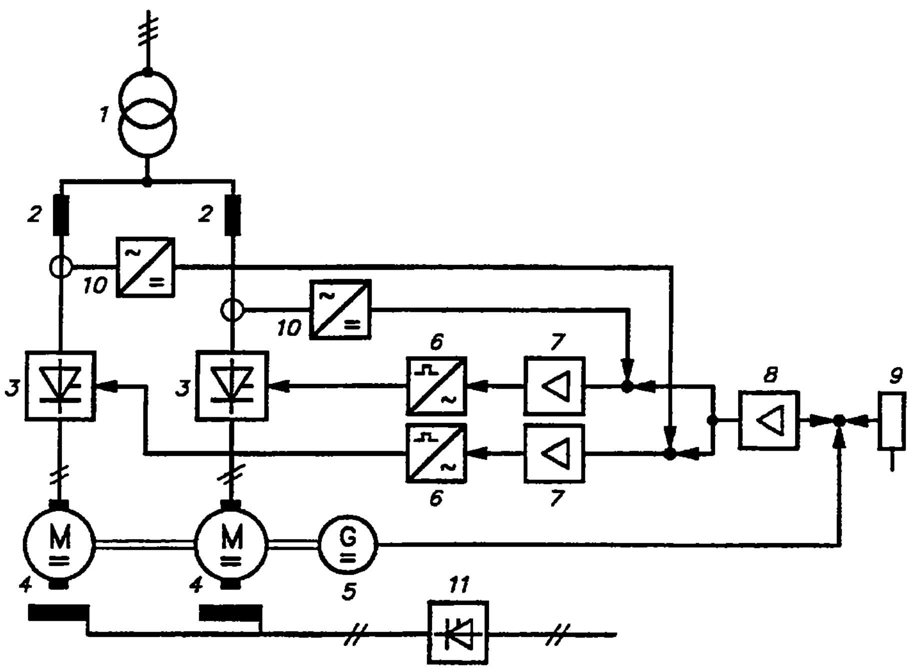
4.2.1.2 Application

The DC drive system is widely used in the cement industry for the following machines:

- kiln main drives — 200 - 500 kW and twin drive
- large fans (e.g. kiln, raw mill) — 800 - 2000 kW
- weigh feeders — 5 - 15 kW
- apron feeders and special belt conveyors — 20 - 100 kW

Due to the rapid developments in power electronics, the variable speed drive technology has gone through various stages in the last decades, but the DC drive represents still an efficient, approved and economic solution today. The commutator, the most delicate part of the whole system, and the cooling system require special and permanent maintenance attention. These two aspects explain the desire for other variable speed drive systems without commutator.

Fig. 34: Typical schematic diagram of a twin drive for a rotary kiln employing thyristor-controlled DC motor



1	Rectifier transformer	7	Current controller
2	Reactor	8	Speed controller
3	Thyristor rectifier, controllable	9	Speed reference potentiometer
4	DC motor	10	Current transformer and rectifier for the current actual value
5	Tacho generator	11	Thyristor rectifier, uncontrollable
6	Gate control unit		

4.2.2 AC drive with squirrel cage motor

The variable speed drive system, using a squirrel cage motor, consists of the following main components (see Fig. 35):

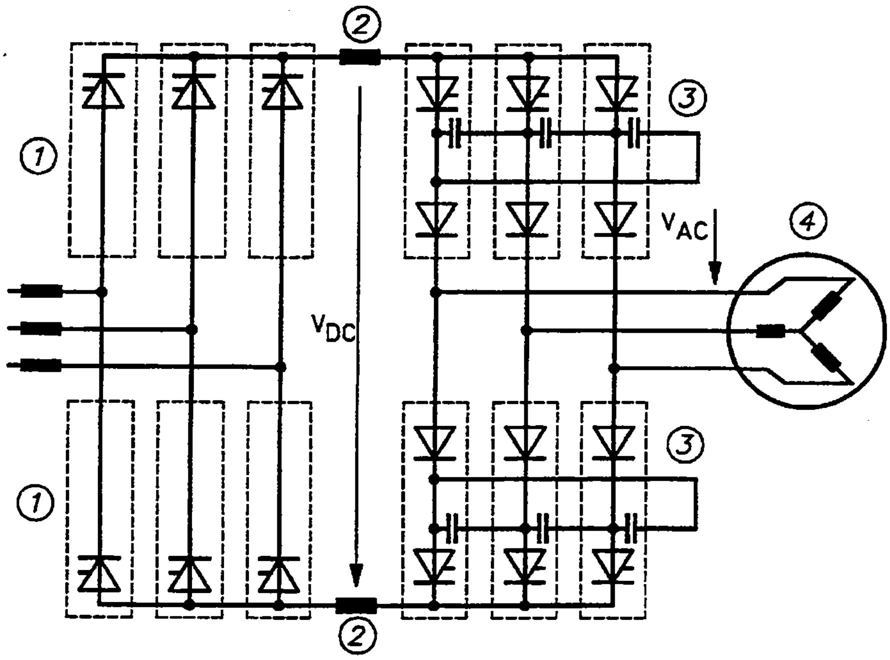
- 3-phase full-wave rectifier (1)
- DC-intermediate link with reactors (2)
- forced commutated inverter (3)
- normal 3-phase squirrel cage motor (4)

An input rectifier creates the intermediate link DC voltage. The reactors inserted in the DC link uncouple the AC power supply side from the inverter side driving the asynchronous motor. The forced commutated inverter is using the principle of phase sequence turn-off. Each of these switching circuits consists of a thyristor, a diode and a commutating capacitor. The input rectifier is current-regulated and supplies its power into the DC intermediate link. The output inverter is voltage regulated, maintaining the correct V/Hz relationship over the speed range. The speed of the motor is adjusted by variable frequency. No tachometer is needed, since the frequency feed-back signal is taken from inside the panel. The normal speed range is from 5 to 50/60 Hz and up to approx. 90 Hz.

The power of the available units presently ranges from 5 kW to approx. 1800 kW of several typical AC input voltage levels like 380, 415, 500, 660 V AC. In special cases, units of 3 MW have been built for all motor speeds up to 4000 min^{-1}.

4.2.2.1 Current-source inverter-fed induction motor

Fig. 35: Frequency converter with phase-sequence turn-off



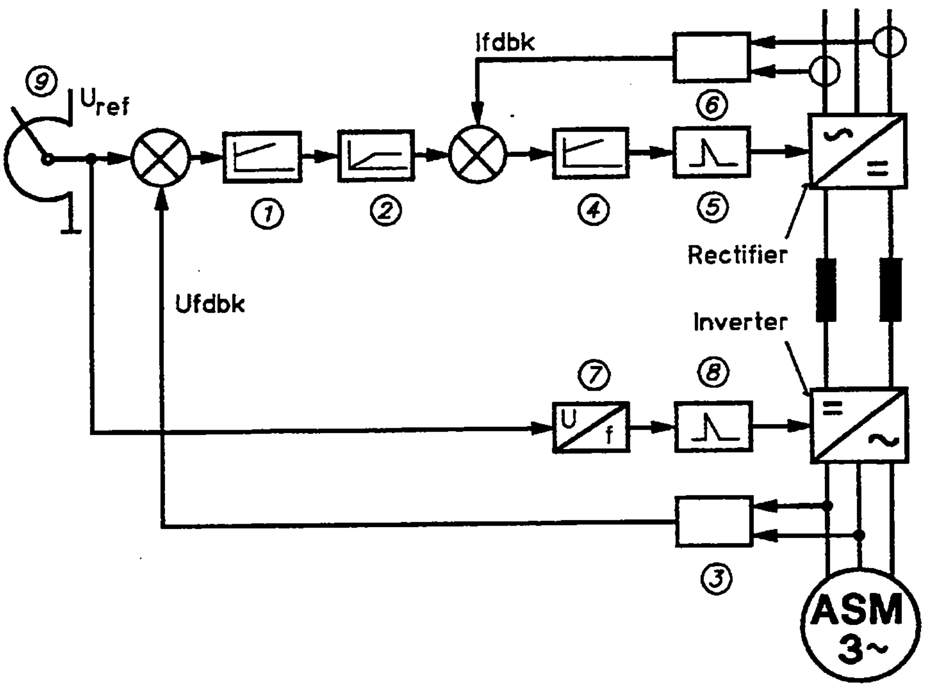
Operating Characteristics

The converter as described above does not need any additional semiconductors in order to perform a full 4-quadrant operation. The flow of energy is reversed by reversing the polarity of the DC link voltage, with the current direction remaining unaltered. At speeds below 5 Hz, torque pulsation may be noted as a result of low frequency motor-current harmonics. This effect is damped by the mass of the mechanical system.

The prevailing use for this type of variable speed drive is to be found with fans and pumps in many different configurations.

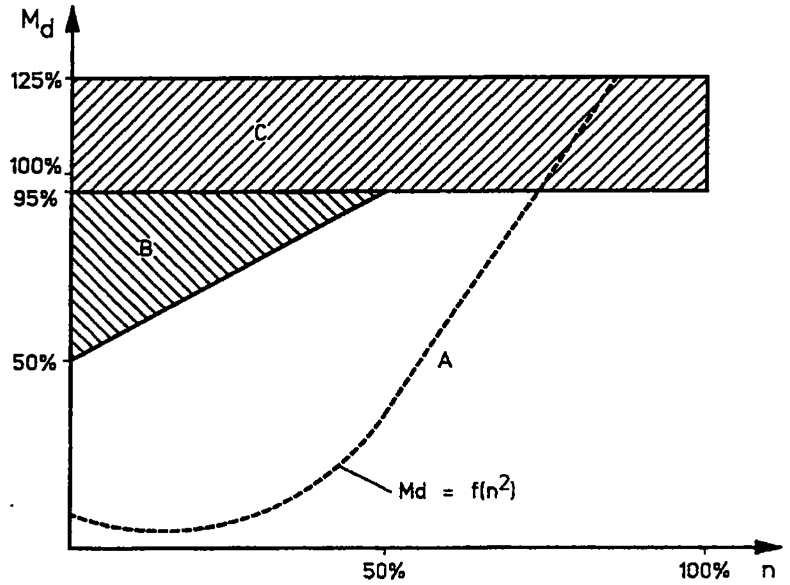
Usually a totally enclosed, fan-cooled standard motor can be chosen with no extra forced cooling system because the torque curve of these mechanical devises follows a square function versus speed.

Fig. 36: Typical block diagram of the voltage-controlled variable frequency converter



1	voltage controller	5	trigger unit of the line-commutated converter
2	value generator and limiter	6	actual current measurement
3	actual voltage measurement	7	voltage/frequency converter
4	current controller (secondary)	8	trigger unit of the self-commutated converter
		9	voltage reference potentiometer

Fig. 37: Torque/speed diagram



A : continuous duty self-ventilated

B : continuous duty with forced ventilation

C : intermittent duty

Application

Cooling equipment manufacturers and suppliers of water pumping stations have used this type of variable speed drive since 1975. Several converter manufacturers have application references for more than 1000 units of a wide power range within the past years.

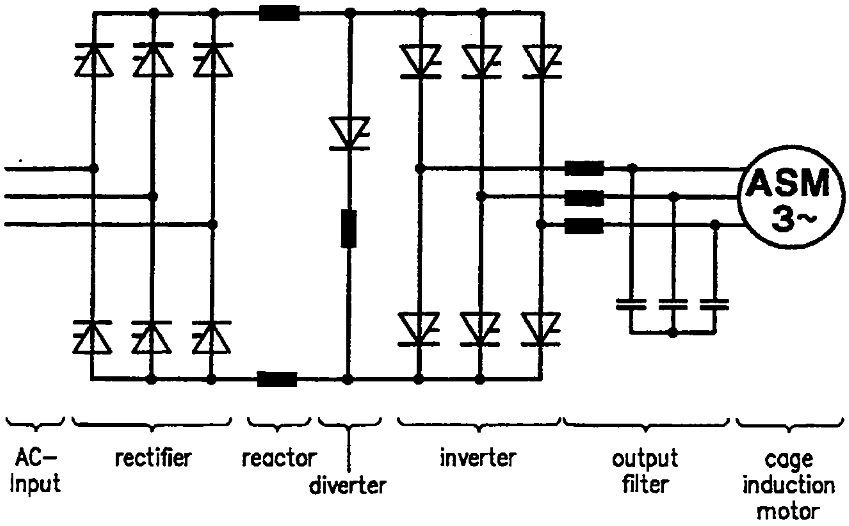
The initial equipment cost is slightly higher than for a comparable DC drive system due to more semiconductor elements in the power path. On the other hand, the squirrel cage motor is much cheaper than the DC motor. Harmonic content and power factor aspects are identical with those of a DC drive since the input rectifier represents the same type of load to the supply side network.

This system offers interesting aspects for modifications of existing equipment. When introducing the variable frequency converter to an installation which was so far connected to a constant 50 or 60 Hz supply, the motor can be speed-controlled. It might be of interest that even a speed-increase is possible by applying more than line frequency (e.g. 70 - 90 Hz). In other words, a belt conveyor can run faster and develop more power without motor - or gear change!

4.2.2.2 Load commutated inverter-fed induction motor

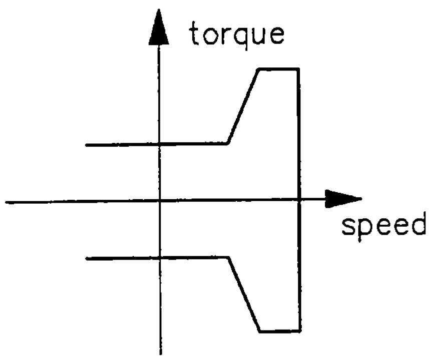
The main components of this drive type consist also of a line-side converter, DC link circuit reactor and load-side converter. Additionally, a so called diverter is added in order to force commutate (switch-off) the inverter at low frequencies, while an output filter is added to smooth output waveforms and provide excitations for the induction motor.

Fig. 38: Cage induction motor with load-commutated inverter (output Filter)



As with the conventional frequency converters, for normal operation the converter is commutated by line-voltage and the inverter is commutated by the load. Unlike the conventional type, the diverter circuit on the DC link is used to commutate the inverter bridge for low frequency operation. The entire inverter is commutated by the diverter, then appropriate thyristors are gated (switched on) to produce the three-phase output. Above about 60% of rated frequency, depending on the motor, the diverter circuit turns off and the inverter is load commutated by the combined effects of the output filter and the induced motor-voltage of the induction motor itself. The filter is sized to provide motor excitation over a wide frequency range. The voltage and current waveshapes are nearly sinusoidal, typically containing less than 5% harmonic distortion at rated output. No motor derating is necessary.

Fig. 39: Torque/speed diagram

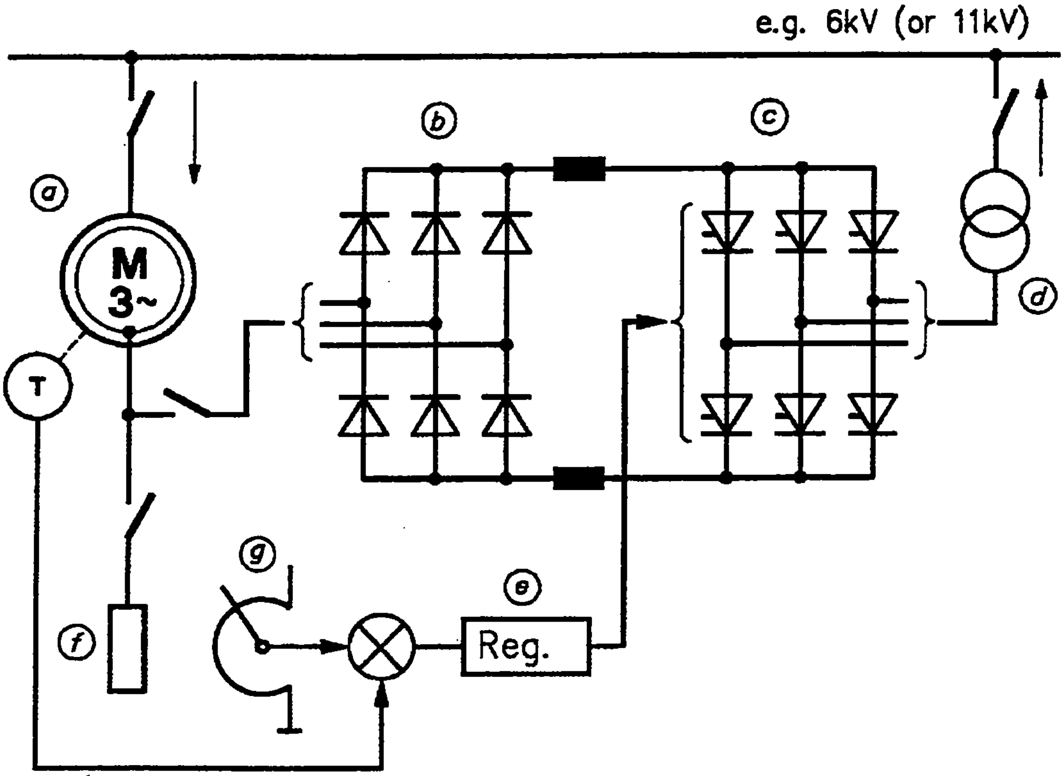


Application

The load-commutated inverter-fed induction motor is best suitable for loads with squared torque/speed characteristic (Fig. 39) and reduced speed range, i.e. for fans.

4.2.3 AC drive with slip ring motor

Fig. 40: Schematic of sub-synchronous cascade



a) HV slip ring motor with tachometer (T)
b) 3-phase full-wave rectifier (diodes)
c) 3-phase full-wave inverter (thyristors)
d) matching transformer
e) electronic speed regulator
f) starting resistor
g) speed reference potentiometer

The stator of the slip ring motor is connected directly to the power system. The rotor slip power, which is proportional to the slip frequency, is fed back into the power system via a diode rectifier, a smoothing reactor, an inverter and a matching transformer. A starting resistor is normally used to drive the motor up to approx. half speed, then the rotor is connected to the converter and the electronic regulator takes over the speed control. The static converter section has to be sized only for the rotor slip power. The sub-synchronous cascade system is mostly used to drive large pumps, fans and compressors, where the torque increases with the square of the speed. A considerable change in capacity is obtained by only a slight adjustment in speed, therefore, a large speed range is normally not required. A range of 2:1 or 3:1 is more than sufficient.

The normal power range for sub-synchronous cascade systems used in industry is from about 500 kW to 10 MW with motor nominal speeds of 1500 min^{-1} or below. For special applications, similar converter systems have been built up to 60 MW. Motor cooling systems are identical to those of normal slip ring motors running at a constant speed.

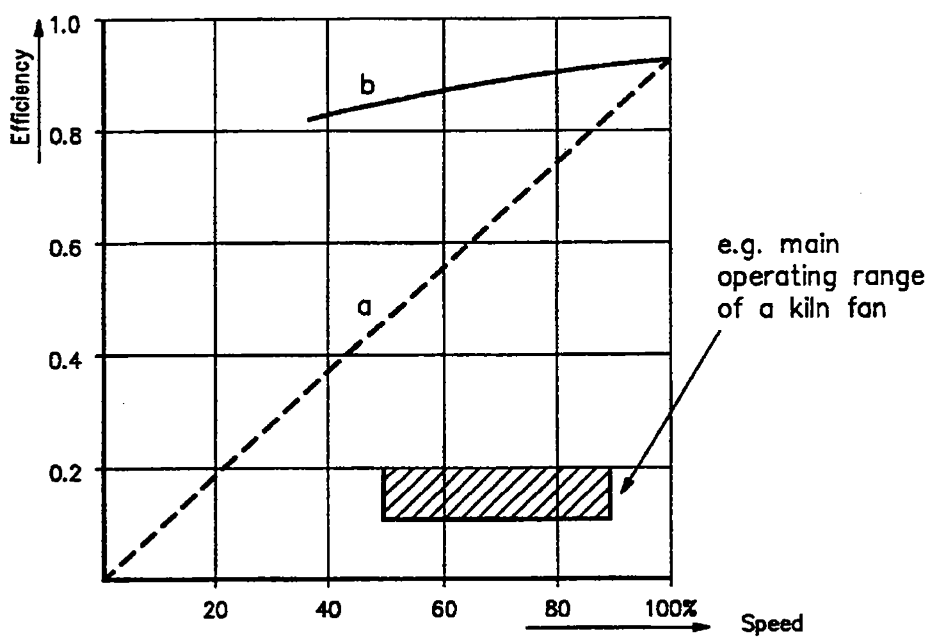
Operating Characteristics

A sub-synchronous cascade drive needs a starting resistor. The variable speed range is very much reduced compared to a DC drive. No oversynchronous speed can be reached and only 1-quadrant operation is possible, i.e. motoring in one direction only.

Every converter requires reactive power. A larger drive systems has a higher demand for reactive power, which has to be considered and compensated. With the sub-synchronous cascade drive system, the reactive power demand increases with increasing speed range. Therefore, the variable speed range should be kept as small as possible. The compensation system has to be designed on an individual basis and should be optimized for the normal running speeds of the motor. Furthermore, the harmonic currents, created by the static converter, have to be considered during the design of the power factor compensation system. In a modern installation, the filter-circuits cover both aspects, resulting in a combination network of reactors and capacitors instead of capacitors only.

The efficiency of the total variable speed drive system is not as high as that of a slip ring motor alone due to more power components being involved in the former. The overall efficiency over the speed range is, however, much better than for example controlling the air-flow with a radial vane damper at constant motor speed or at variable slip ring motor speed using permanently connected resistances in the rotor circuit.

Fig. 41: Typical speed/efficiency curve of a sub-synchronous cascade drive



a : variable speed by rotor resistance
b : variable speed by sub-synchronous cascade

Application

Especially large plants require large fans where DC drives are not feasible as the power/speed ratio exceeds the typical DC motor frame size. Here, the sub-synchronous cascade system offers an interesting alternative.

A 2000 t/d plant, for example, needs a kiln fan of 1700 kW at 1500 min^{-1}. Large fans in the cement industry can have a range of up to 5 MW. Therefore, this type of drive will be seen in our industry more often since it meets all requirements in terms of controlability, operating behaviour and economy.

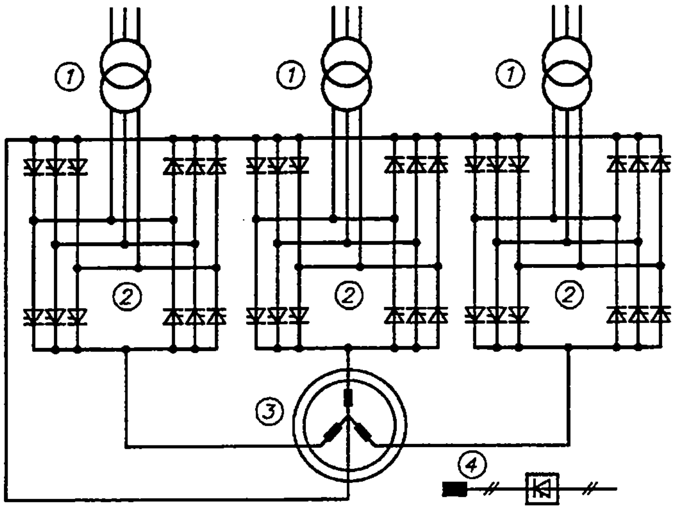
Furthermore, any existing slip ring motor can be converted into a variable speed drive by adding a sub-synchronous cascade converter system. On the other hand, every cascade system can run at rated motor speed without the static converter, e.g. during a fault in the electronic regulation part. Leaving the mechanical flow control device installed will be of advantage!

The sub-synchronous cascade drive is, therefore, a technically and economically favourable system for large fans requiring variable speed du to process parameters.

4.2.4 AC drive with synchronous motor

4.2.4.1 Synchronous motor with cyclo-converter

Fig. 42: Converter schematic used in conjunction with the ring motor (gearless mill drive)



1) converter transformer
2) two converters in anti-parallel three-phase bridge connection
3) synchronous motor
4) exciter winding

Each motor phase is connected to the feeding power system via two static converters arranged in an anti-parallel three-phase bridge network. A low frequency output voltage is delivered by the converters by means of phase angle control. At a system frequency of 50 Hz, the maximum attainable output frequency is approx. 20 Hz. With this drive system, four-quadrant operation, i.e. reversal of the direction of rotation and regenerative braking, is possible without any modification. This system corresponds fully to a four-quadrant DC drive. A high starting torque and almost sinusoidal current results in particularly favourable characteristics at low speeds.

This system is well-suited for the substitution of large DC drives, e.g. for conveying machinery, in rolling mills or as propeller drives for ice breakers and mine winders, especially when the DC motor can no longer be employed because of ambient conditions, maintenance costs or power limits.

The system covers a range from 1 to 20 MW.

4.2.4.1.1 Application

The cement industry uses this system only for large (cement) mills, avoiding the gear and, therefore, saving space and building cost. Of course, this is not of equal importance all over the world and its technical complexity can be a drawback in many third world countries. Therefore, this drive system is not very often selected. But in other industries, it will replace in the near future more often the large DC machines in the MW-range.

4.2.4.2 Synchronous motor with intermediate circuit converter

Fig. 43: Basic circuit, 6-pulse

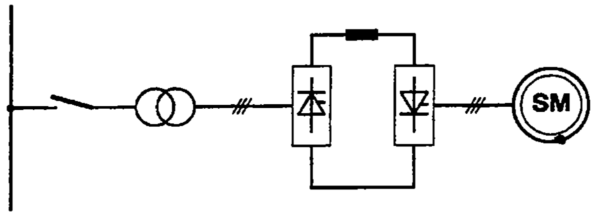
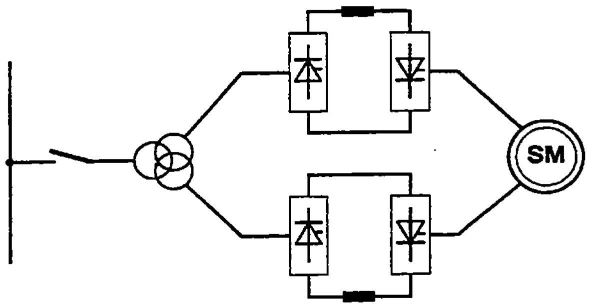


Fig. 44: Basic circuit "12-pulse"



Rectifier and inverter, "12-pulse" with two motor windings displaced by 30° el.

Static converter in parallel connection

The circuit is generally called a converter-fed synchronous motor and consists of a controllable rectifier, a smoothing reactor and an inverter. In these designs (Figures 43 and 44 above), rectifier and inverter have to be sized for the full motor power, compared to the sub-synchronous cascade, where the converter has to cope with the rotor slip power only. The commutation from one phase to another of the inverter is dictated by the terminal voltage of the synchronous machine. This natural commutation does not need any additional circuit like e.g. the forced commutation with the converter type for squirrel cage motors.

This type of converter is suitable for 4-quadrant operation and can cover a full speed range like a DC drive variable speed system.

The 6-pulse scheme is normally used for power of 1 to 5 MW. For larger systems, the harmonic currents lead towards 12-pulse configurations due to motor and line side problems. Modern synchronous motor drives have a brushless excitation system. An auxiliary asynchronous machine, integrated into the synchronous motor, supplies its power through a rotating diode rectifier to the DC field winding thus avoiding trouble causing slip rings.

Converter frequencies of up to 120 Hz can be realized driving a two pole synchronous motor up to 6000 min^{-1} at almost any power. Systems of 30 MW have been built and projects of 50 MW are being studied.

4.2.4.2.1 Application

The main applications of the converter-fed synchronous motor for pumps, extruders and compressors, where a precise speed control over a wide speed range is important.

These drives are not installed in the cement industry, as the existing type of machinery does not specifically require a converter-fed synchronous motor system.

4.2.5 Electronic smooth-start for three-phase motors (soft starters)

The simplest and cheapest way to start a three-phase motor is full-voltage, across the line starting, and that method should be used whenever feasible. But there has always been a need in some applications to limit the locked-rotor inrush current to the motor, control motor starting torque, or both.

Control of starting torque and acceleration is often required to protect the dirven-load. For example, it might be necessary to control acceleration and starting torque of a conveyor motor to prevent shock damage to system elements and damage to products on the conveyor.

Fig. 45: Electronic soft-start for a three-phase motor

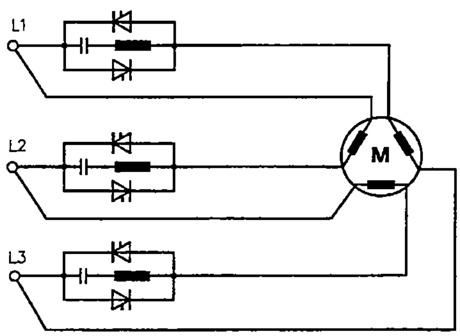
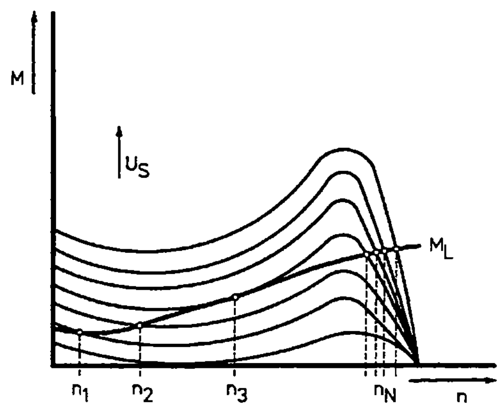


Figure 46 shows the course of torque with a smooth-start for a three-phase motor. The starting procedure begins by 20 to 40% of the nominal voltage. During the adjusted starting time, the stator voltage will be increased to 100% through the control of the firing-angle of the thyristor-controllers.

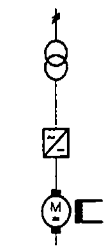
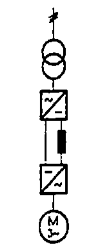
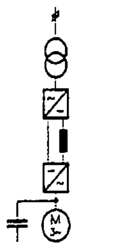
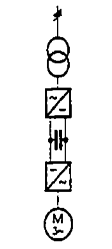
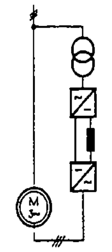
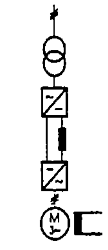
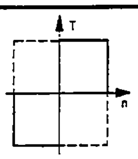
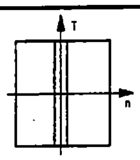
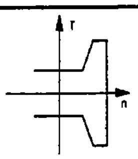
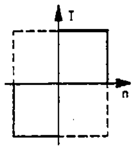
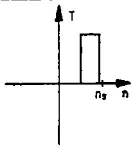
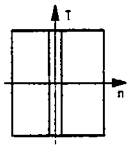
The motor runs up along the load characteristic Ml, whereby torque-shocks will be avoided. The speed increases linear during the starting time from 0 to the nominal speed of the motor. After the starting procedure, when the motor runs with nominal load, the thyristor will be fully conducted.

The electronic smooth-start works similar to the hydrodynamic coupling (see chapter 4.3.3), but it has the decisive advantage that the starting time and the starting torque can be easier adjusted to the individual operating conditions.

Fig. 46: Torque/speed diagram



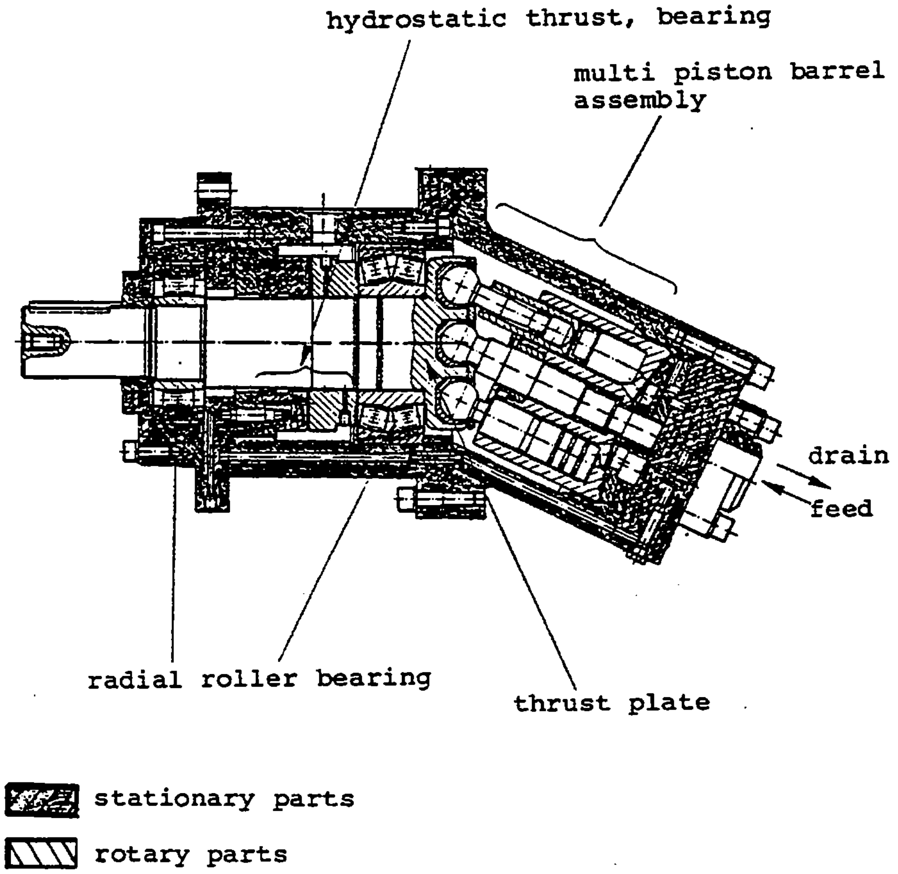
Summary of large variable speed drive systems for the cement industry (>1 MW)

Drive system	Direct Current Drive	Current-source inverter-fed induction motor	Load-commutated inverter-fed induction motor	Voltage-source inverter-fed induction motor (PWM)	Wound-rotor induction motor with subsynchronous converter casode	Converter-fed synchronous motor	Drive system
System diagram							System diagram
Type of machine	*Direct Current Motor*	*Cage induction motor*			*Wound-rotor induction motor*	*Synchronous machine*	Type of machine
Operating range T: torque n: speed							Operating range T: torque n: speed
Typical power range	up to 2000kW	up to 2000kW	500 ... 5000kW	800 ... 5000kW	500 ... 5000kW	1000 ... 10000kW	Typical power range
Typical speed range	0 ... 100%	2 ... 100%	65 ... 100%	0 ... 100%	50 ... 98% of synchronous speed	(0) ... 10 ... 100%	Typical speed range
Significant properties	Single-motor drive of medium power Good performance also at low speeds	Single-motor drive of medium power Applicable normally for loads with squared torque/speed characteristic	Single-motor drive with nearly sinusoidal motor current and voltage Applicable normally for loads with squared torque/speed characteristic	Single- or multi-motor drive Good performance also at low speeds Power-factor to line nearly unity	Slip-power recovery Economic for small motor-speed-control-range High starting torque Suitable for retrofitting of existing slipring motors	Single-motor drive of high power High speed possible	Significant properties
Suitable for	Fan, Kiln	Fan	Fan	Fan, (Kiln)	Fan	Fan	Suitable for
Price [%] Base: 1500kW/1000RPM	100%	105%	110%	110%	85% (without filter!)	140%	Price [%] Base: 1500kW/1000RPM

4.3 Hydraulic variable speed drive system

4.3.1 Hydrostatic drives

Fig. 47: Scheme of a hydrostatic motor



The hydrostatic motor is connected to a hydraulic high pressure pump system. The oil feed and drain pipes are located on the opposite side of the drive shaft.

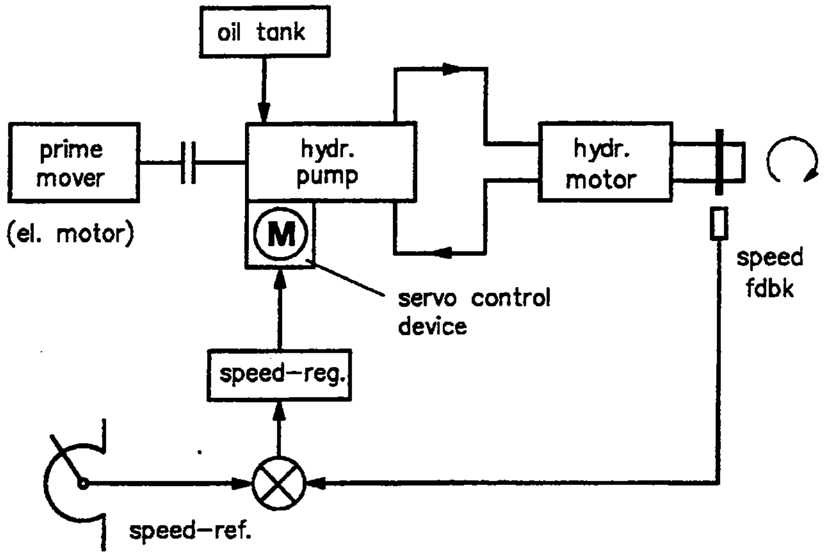
The unit can be subdivided into two parts i.e. the drive shaft bearing part and the torque creating multi-piston barrel assembly. Due to the inclined mounting of the piston barrel assembly, continuously varying cylinder volumes exist during one revolution. The pistons, therefore, perform strokes similar to those of an automobile-engine. The high-pressured oil enters and leaves through slots acting as valves. The piston forces react on the thrust-plate, causing the cylinder barrel and attached shaft to rotate with a torque proportional to the supplied oil pressure. The rotation speed of the motor shaft changes proportionally to the supplied oil-flow.

The hydrostatic motor parameters are:

- oil pressure → torque
- oil flow (quantity) → speed

These two variables are supplied to the motor by a hydrostatic pump driven by a prime mover and the associated speed control regulation devices.

Fig. 48: Main components of a hydrostatic variable speed drive system



The hydrostatic pump basically consists of the same elements, only the multi-piston barrel assembly does not have a fixed inclined angel. The complete piston unit is designed to swivel about a transverse trunnion axis. At zero degree deflection, all pistons remain axially at the same position, i.e. do not perform any stroke and, therefore, no oil-flow is created. Moving the piston unit out of the straight centre line, the pistons start to execute a stroke proportional to the deflection angle. An oil flow is established and the motor starts to turn at a speed proportional to the deflection angle.

Fig. 49: Plan view of a hydrostatic pump with piston unit at 0 degree deflection

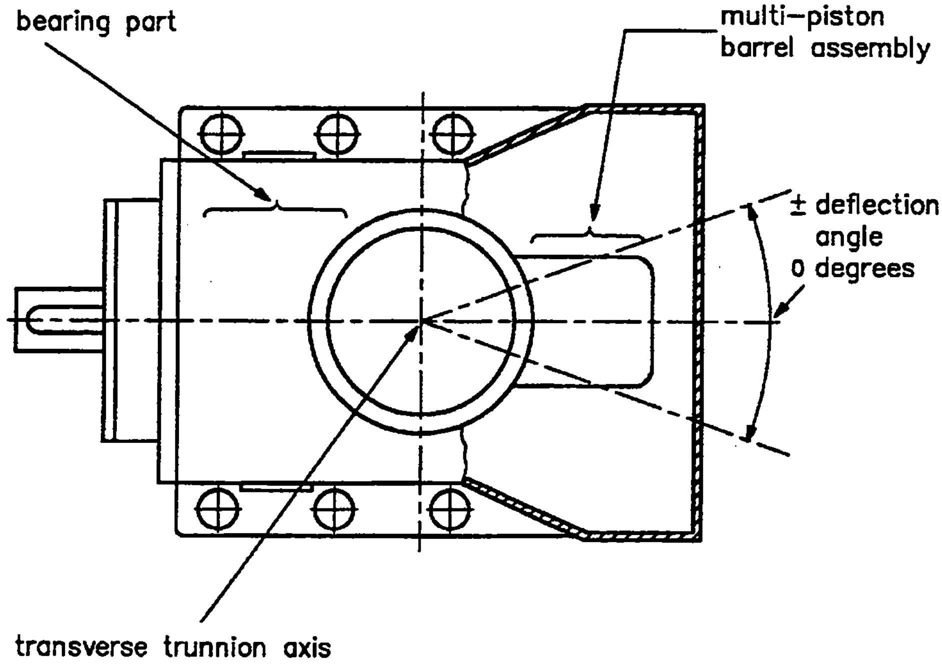
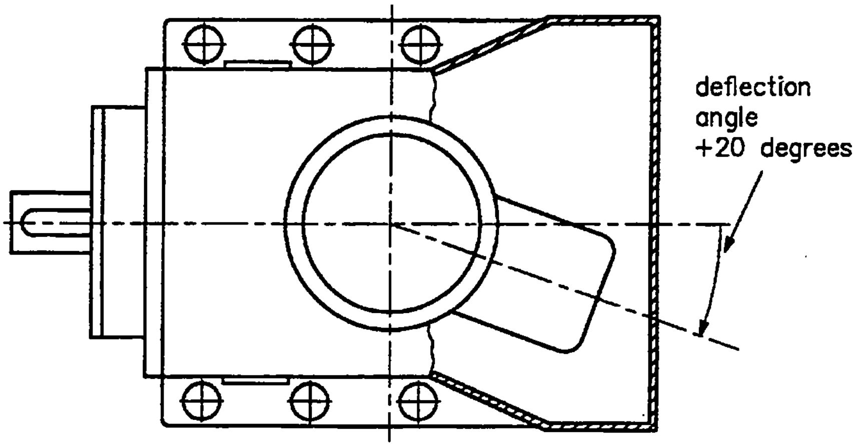


Fig. 50: Plan view of a hydrostatic pump with piston unit at +20 degrees deflection



This is a short introduction to the hydrostatic operating principle. Many additional accessories like valves, oil cooler, operating protection, torque limiters, emergency shut-down, etc. are not explained, but are available and together with pump and motor form a complete drive system. Good operating behaviour and controllability therefore make it truly comparable to electrical variable speed drive systems.

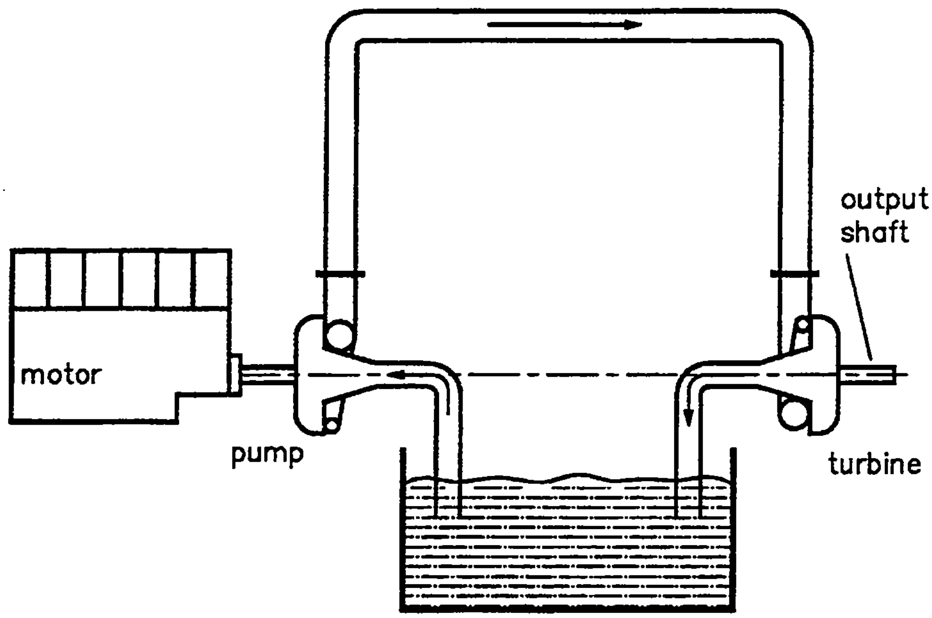
4.3.1.1 Application

The hydrostatic drive system is widely known and used in the cement industry since approx. 1965. Drives requiring variable speed and high starting torque have been equipped with the above system, e.g. for crusher-feeders, grate coolers, etc. from a few kW-approx.-200 kW. Good reliability and low maintenance of this hydromechanical system make it an alternative to electrical drives.

4.3.2 Hydrodynamic drives

The construction of a hydrodynamic drive is similar to that of a turbine, where rotor and stator are not in direct mechanical contact, but are coupled through a liquid or gaseous medium. A prime mover (e.g. electric motor) drives a hydraulic pump. The medium set in motion by the pump is feeding a hydraulic turbine which at its output shaft drives the coupled machine requiring smooth-start or variable speed.

Fig. 51: Operating principle of a hydrodynamic coupling



Pump and turbine are brought together and built into one common casing. This combined unit is then called hydrodynamic coupling or turbo coupling.

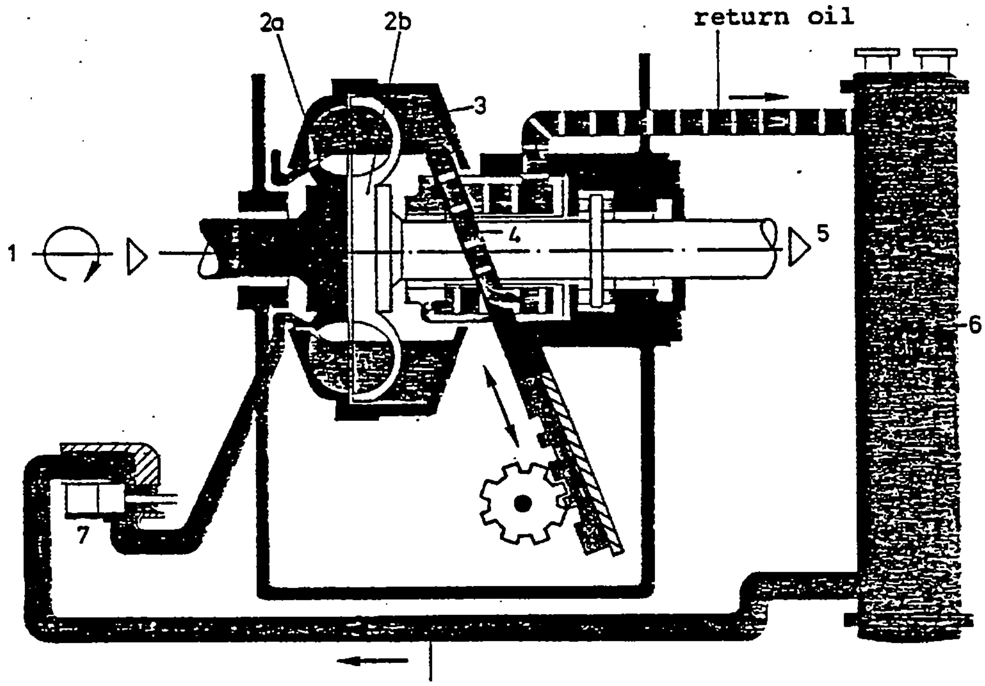
In most commercially used types of couplings, the medium which transports the kinetic energy from the pump to the turbine is oil. The quantity of oil represents a very important parameter since the transmitted torque and speed depend on the filling degree of the coupling.

Therefore

- constant oil volume → coupling
- variable oil volume → variable speed drive

In order to achieve a variable oil volume, technical means of adding to and subtracting from the oil volume have to be established during operation at any speed. This oil quantity e.g. can be varied with an adjustable sliding scoop tube. In this way, the power transmitted by the hydrodynamic coupling can be adjusted and stepless speed regulation of the driven equipment in accordance with load demands is provided.

Fig. 52: Schematic diagram of a variable speed hydrodynamic coupling



1) prime mover (e.g. electric motor)
2) hydrodynamic coupling:
   a : pump, b: turbine
3) oil level in the casing during operation
4) adjustable sliding scoop tube (up and down)
5) output shaft with variable speed depending on scoop tube position
6) heat exchanger
7) oil flow control valve

4.3.2.1 Application

The hydrodynamic coupling itself behaves according to the propeller law. The output torque increases with the square of the input speed. The coupling, therefore, is well-suited to drive machines with parabolic torque load characteristics such as centrifugal pumps and fans with a regulating range of not more tan 4:1. Machines with a constant torque load characteristic can be used only with a speed range of not more than 3:1 and have to be oversized in most cases. Dynamic response of the variable speed drive system is much slower than e.g. with a DC drive since this depends on the position regulator of the scoop tube.

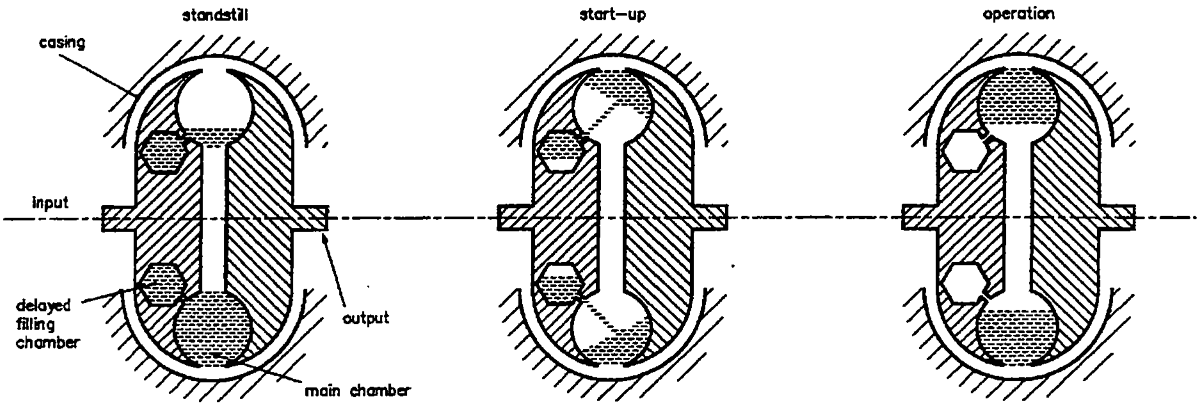
On the other hand, the hydrodynamic offers very interesting benefits since very large units at very high speed are quite normal. The size ranges from a few kW (approx. 20 kW) up to 8 MW at 12,000 min^{-1} or 60 MW at 5,000 min^{-1}. Especially the units with extreme speed requirements (very high or low) operate either at the input or output with multiple gear stages.

Many of those very large and high speed units are installed in nuclear and thermal power plants as boiler feed pumps. Others, including the cement industry, use some of the wide variety of hydrodynamic variable speed drive systems too.

4.3.3 Smooth-start by turbo couplings

The operating principle of the hydrodynamic or turbo coupling is described in para 4.3.2 above. The main feature of such a device is not the speed regulation, but the soft start and shock absorbing characteristic. The final output speed at the end of the start-up sequence is, therefore, always similar to the input speed. The plain coupling has no scoop tube. One of the special features is the retarded filling of the oil chamber after stand-sill. During start-up, the integral delayed filling chamber retains part of the operating fluid from the coupling working chamber, resulting in a reduced torque transmission until all the oil has reached the main chamber. This allows the electric motor to start-up under virtually no load.

Fig. 53: Principle of operating of the delayed filling chamber



The total oil volume is also a measure to control the maximum transmittable torque. In a multi-motor belt system, e.g. load balance can be adjusted by the individual oil filling.

4.3.3.1 Application

The family of hydrodynamic couplings is well-known in the cement industry. Soft or controlled start-up can be achieved by a slip ring motor and the corresponding size of the rotor resistor. A squirrel cage motor and a hydrodynamic coupling perform the same task more elegantly. Therefore, heavy starting machines like long belts, crushers, fans with a large external mass are often equipped with hydrodynamic couplings as well as mechanical items which do not permit excessive starting torque stresses like chains on bucket elevators. This type of coupling is available from 1 kW up to approx. 1,500 kW at nominal input speeds of 3,000 $min._1$ for the small units and 1,000 $min._1$ for the larger ones.

5. CRITERIA FOR ASSESSMENT

5.1 Specifications

In the specifications the operational requirements, standard of manufacture and the stipulated reliability have to be summarized by the user. Apart from the technical details generally given and the ambient conditions, a number of other factors are important for variable-speed drives:

- Starting and slow-running characteristics
- Speed/torque characteristic of the driven machine and of the selected drive system
- Range of operating speed and accuracy
- Suitable means of protecting the installation, which does not lead to unnecessary stops in the event of short interruption of the supply
- Definition of the maximum admissible harmonic current content on the network and of the filter equipment
- Extent to which the power electronics is proof against short circuits
- Cooling for the motor and converter
- Redundancy requirements

5.2 Reliability

The main objective when using any drive system, be it mechanical or electrical, is to ensure high availability and reliability for the installation as a whole, with minimum maintenance. The choice of system can to a large extent be influenced by the qualifications of the local staff. This does not only apply to electric drive systems; hydromechanical systems today use components and technologies which can no longer be regarded as common knowledge for the average mechanic. On the other hand, the electrical industry, by utilizing high-power thyristors and by simplifying the control electronics, is making an attempt to keep the complexity of the systems within reasonable limits.

5.3 Efficiency

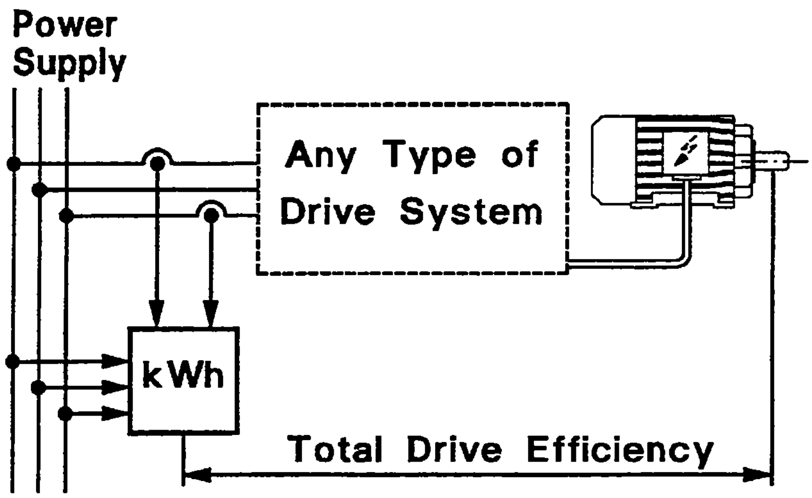
As far as running costs are concerned, the efficiency at the most frequently used operating point is a factor of decisive importance. In the foreseeable future energy costs will continue to increase at a faster rate than investment costs. Therefore, when planning installations, it is necessary to make a comparison of the investment cost with the operating costs of the potential drive systems. This trend should be taken into account in the appropriate manner during the evaluation.

The efficiency figures quotated by the manufacturers of drive systems have to be examined with great care, as in most cases they only provide an efficiency curve for full load of the most significant drive component, e.g. the motor. Information on partial load is difficult to obtain, but in most cases the values are below those quoted.

5.3.1 Definition of total drive system efficiency

Efficiencies of individual drive components do not define the total system behaviour. For comparison, it is therefore essential to establish meaningful and measurable limits, which define the border lines of efficiency for one total drive system. On the one hand, the power drawn from the network is measured and, on the other, the mechanical power imparted at the variable speed shaft. All components located between these two interfaces are appropriately to be taken into account for any system including auxiliary power consumption e.g. for cooling or ventilating purposes.

Fig. 54: Definition of total drive system efficiency



6. CONCLUSIONS

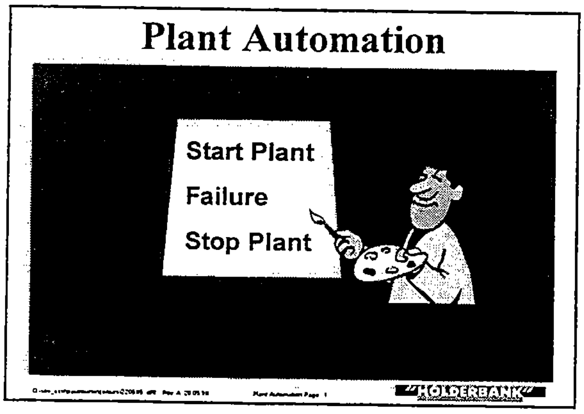
Especially when high powers are involved, existing and newly planned installations should be closely examined to determine whether they are not equipped with drives or control systems involving unduly heavy losses. Using up-to-date techniques, this is a field where it is possible to achieve substantial savings in running costs.

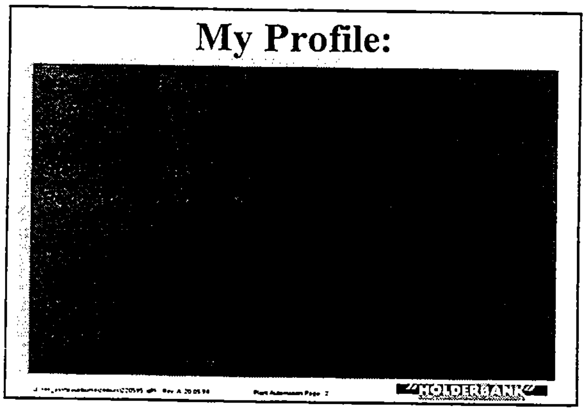
It may be taken for granted that the present trend towards variable-speed drive systems fed by static converters will continue in the future. The development of power and control electronics also allows one to expect that the outlay for variable-speed a.c. drives will decrease further. The high effieciency of electric drives will therefore make their utilization increasingly interesting. The trendency to seek an alternative to d.c. motors and thus to get away from their commutator problems, is unmistakeable. Opportunities for this are provided by hydromechanics and three-phase a.c. systems. But even these systems require a certain amount of maintenance. It is therefore advisable to analyse all alternatives very closely. No matter how high the efficiency may be, it loses all its significance if the system fails only a few times! It will therefore be necessary to weigh reliability and efficiency very thoroughly, one against the other.

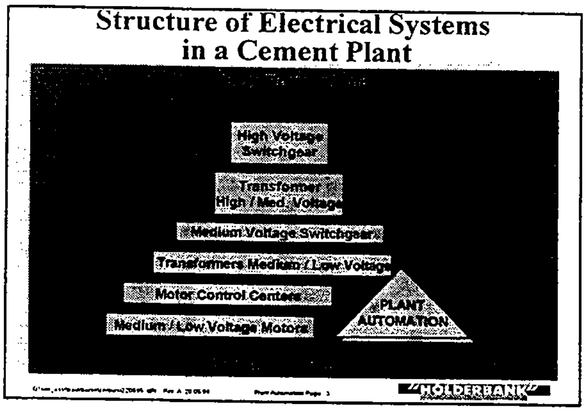
Some typical applications of variable-speed drive systems were dealt with in this session. Unfortunately there are not generally valid solutions for the various applications in all countries.

7. MESSAGES

- Be energy conscious when selecting variable speed drives
- Consider alternatives and new technologies
- Analyse new technologies very thoroughly especially with respect to reliability and efficiency


Plant Automation
Start Plant
Failure
Stop Plant
"HOLDERBANK"

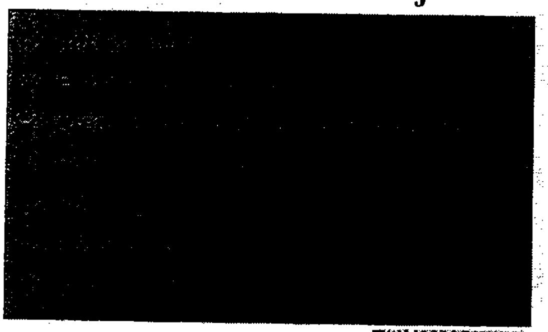

My Profile:
"HOLDERBANK"


Structure of Electrical Systems
in a Cement Plant
High Voltage Switchgear
Transformer High / Med. Voltage
Medium Voltage Switchgear
Transformers Medium / Low Voltage
Motor Control Centers
Medium / Low Voltage Motors
PLANT AUTOMATION
"HOLDERBANK"

Structure of Electrical Systems in a Cement Plant

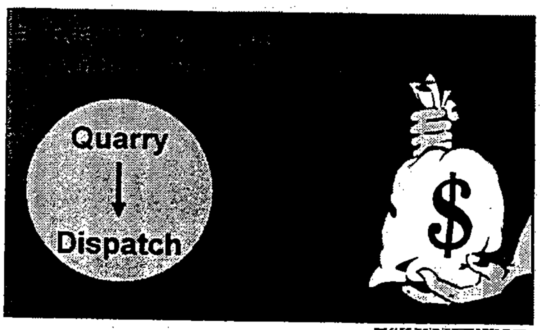
"HOLDERBANK"

Plant Automation Subjects:



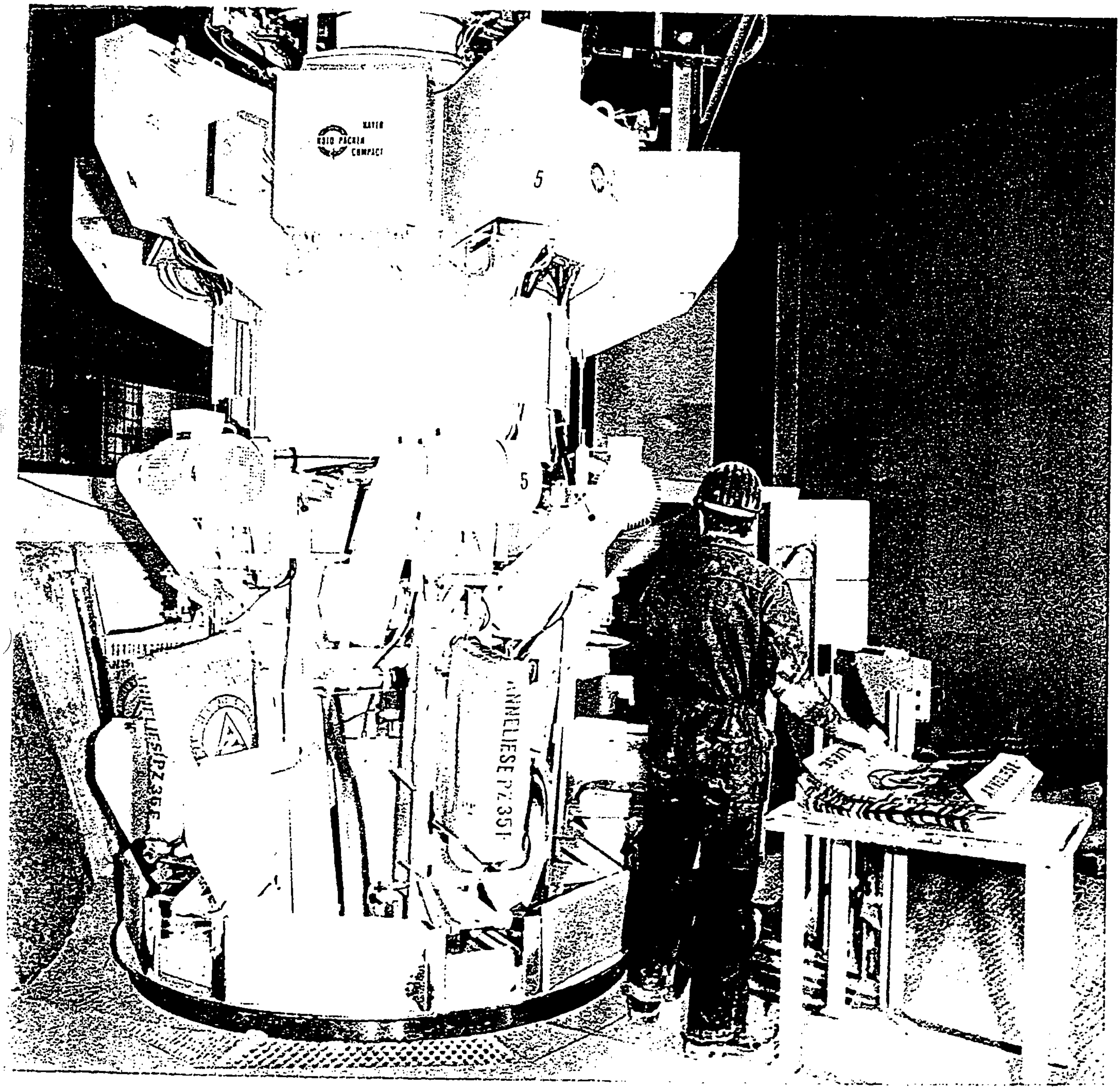
"HOLDERBANK"

Definition of Automation

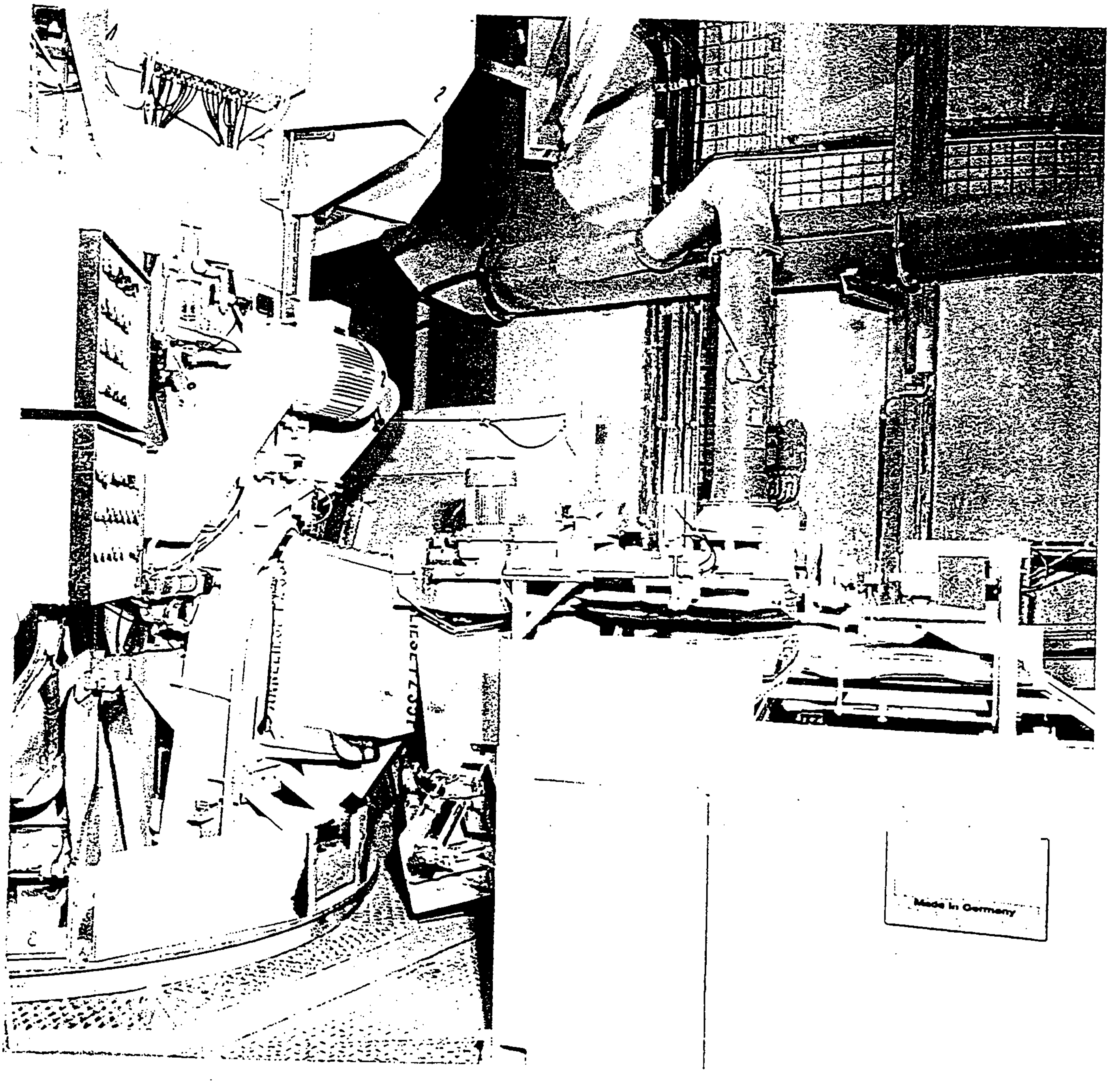


"HOLDERBANK"

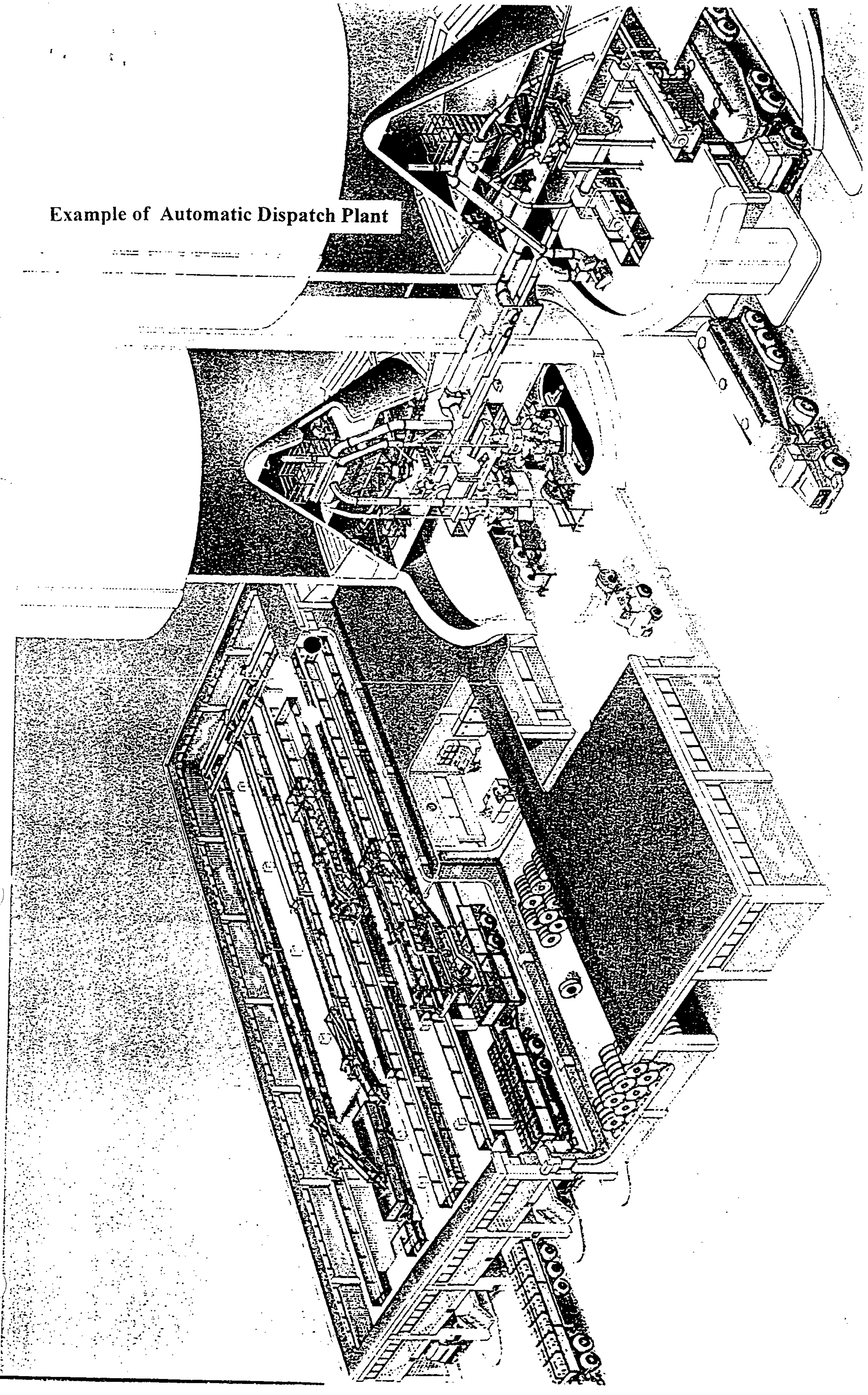
Example of Manual Bag Loading



Example of Automatic Bag Loader

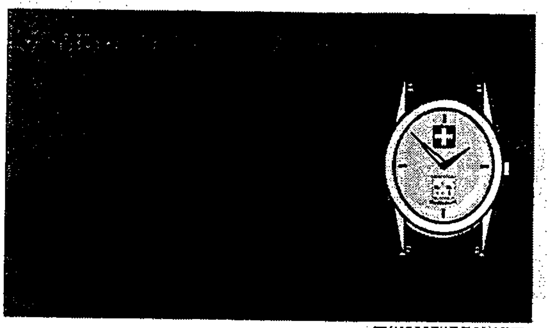


Example of Automatic Dispatch Plant

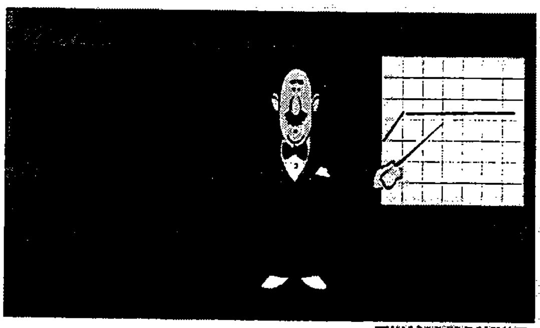


Benefits of Automation ?

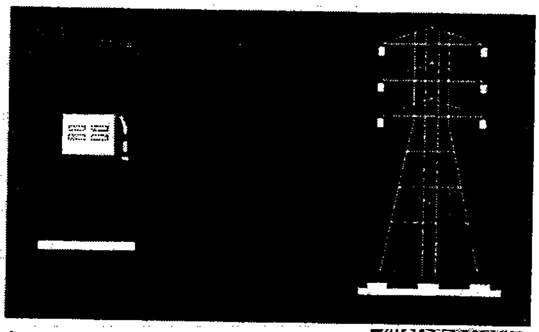
Benefits of Automation



Benefits of Automation



Benefits of Automation

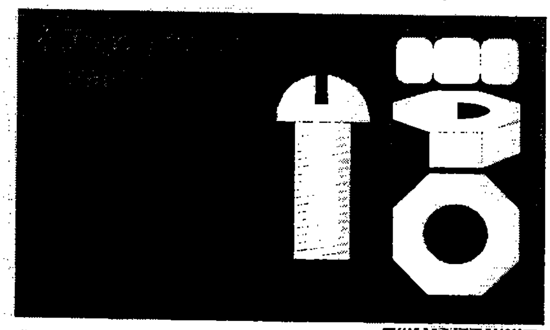


"HOLDERBANK"

Benefits of Automation

"HOLDERBANK"

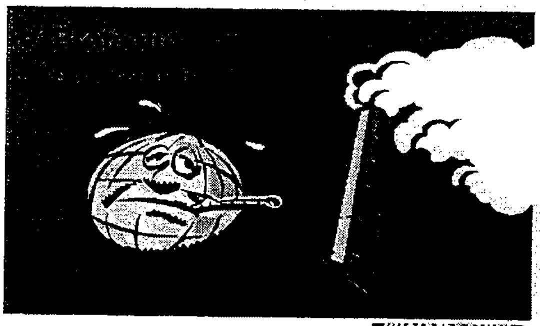
Benefits of Automation



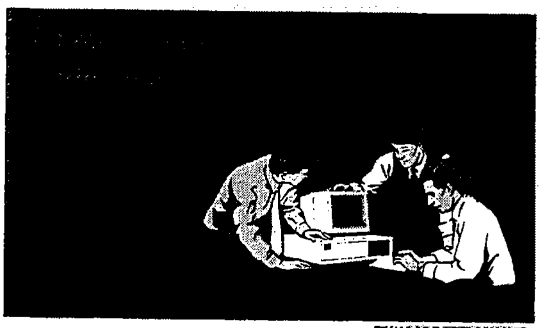
"HOLDERBANK"

Benefits of Automation

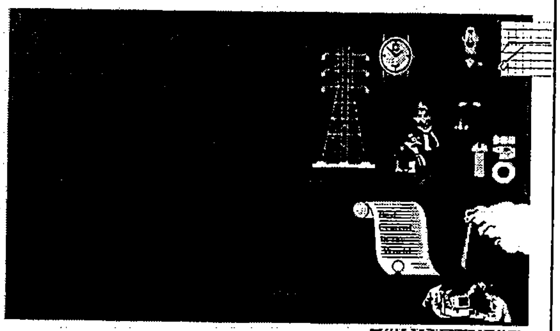
Benefits of Automation



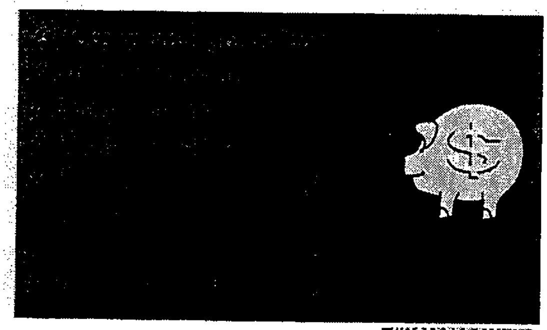
Benefits of Automation



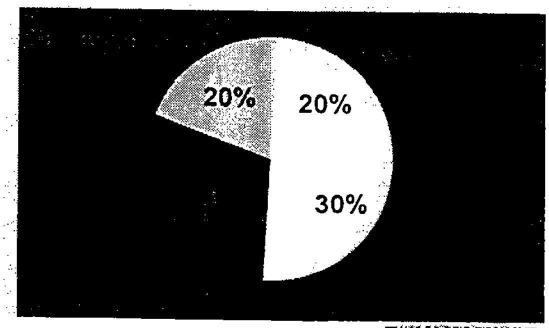
Benefits of Automation



Benefits of Automation

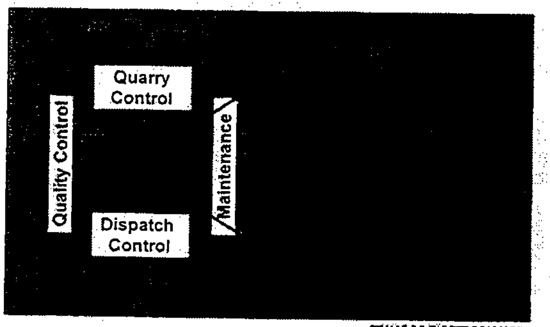


Allocation of Production Costs

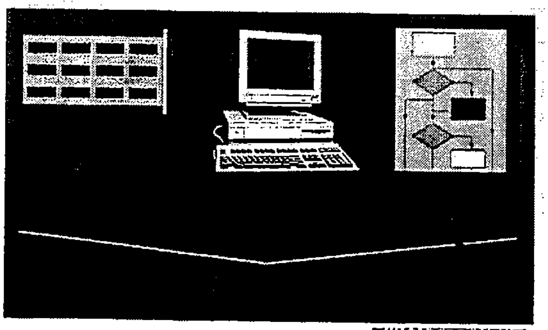


Production Costs

Areas of Automation in a Cement Plant



Automation ?

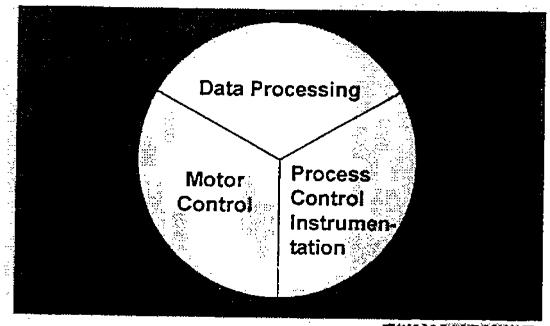


History of Automation Systems

Year	Complexity of Control.	Plant Sitze
1940	Local control of individual machine, local pneumatic/mechanical indication.	50 Motors, 20 Instruments
1960	Central control rooms, sequence control of motors (by relays), some remote indication of instruments.	200 Motors, 70 Instruments
1975	CCR's decentralized programmable controllers, monitoring- or process computers.	400 Motors, 150 Instruments
1985	Centralized controllers with remote I/O's, graphic displays, communication links.	800 Motors, 300 Instruments
1990	Distributed control systems, optical cables, automated documentation tools, integration of management information.	1000 Motors, 500 Instruments
1995	Optimized haman-machine interface, Fuzzy logics, high level control.	1000 Motors up to 600 Instr.
1998	Field Bus technology for analog and digital sensors/actors.	
Future	unattended factory ??	more Instruments

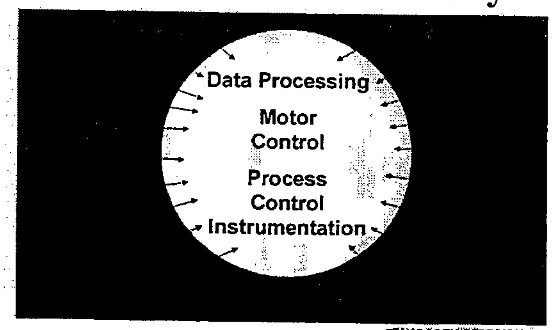
"HOLDERBANK"

Traditional Automation



"HOLDERBANK"

Process Automation today

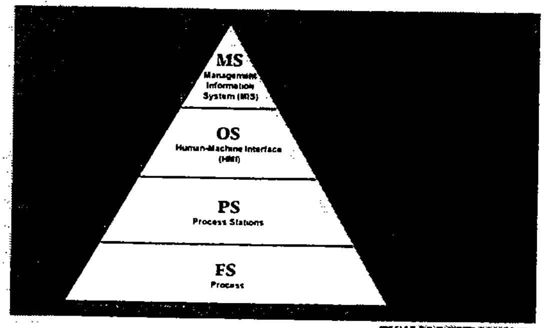


"HOLDERBANK"

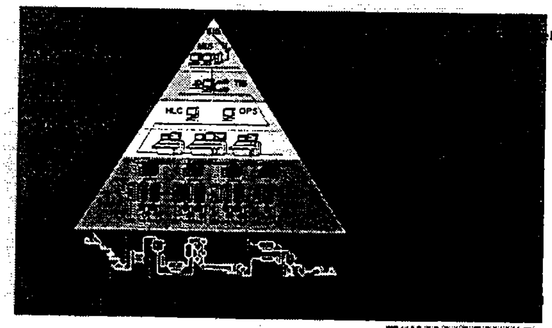
Automation Today

- Automation no longer refers to a control system of an industrial plant or facility
- It now refers to the entire electrical system which needs to operate and communicate as one integrated system from the main HV substation all the way to the motor and the device
- No information islands in the system

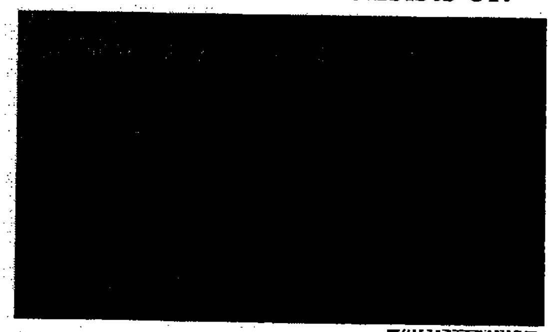
Structure of Plant Automation



CIM - PYRAMID



The Field Level consists of:

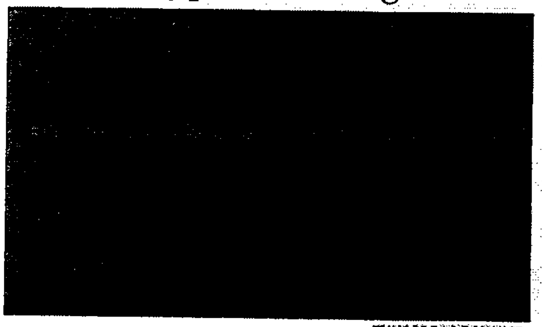


Per Production Line

Today		Future
6'000	Digital Inputs	8'000
1'300	Digital Outputs	2'000
350	Analog Inputs	1'000
40	Control Loops (PID)	70
10'000	Alarmpoints	15'000
150	Calculated Values	500
1'000	Archived Values per Minute	4'000

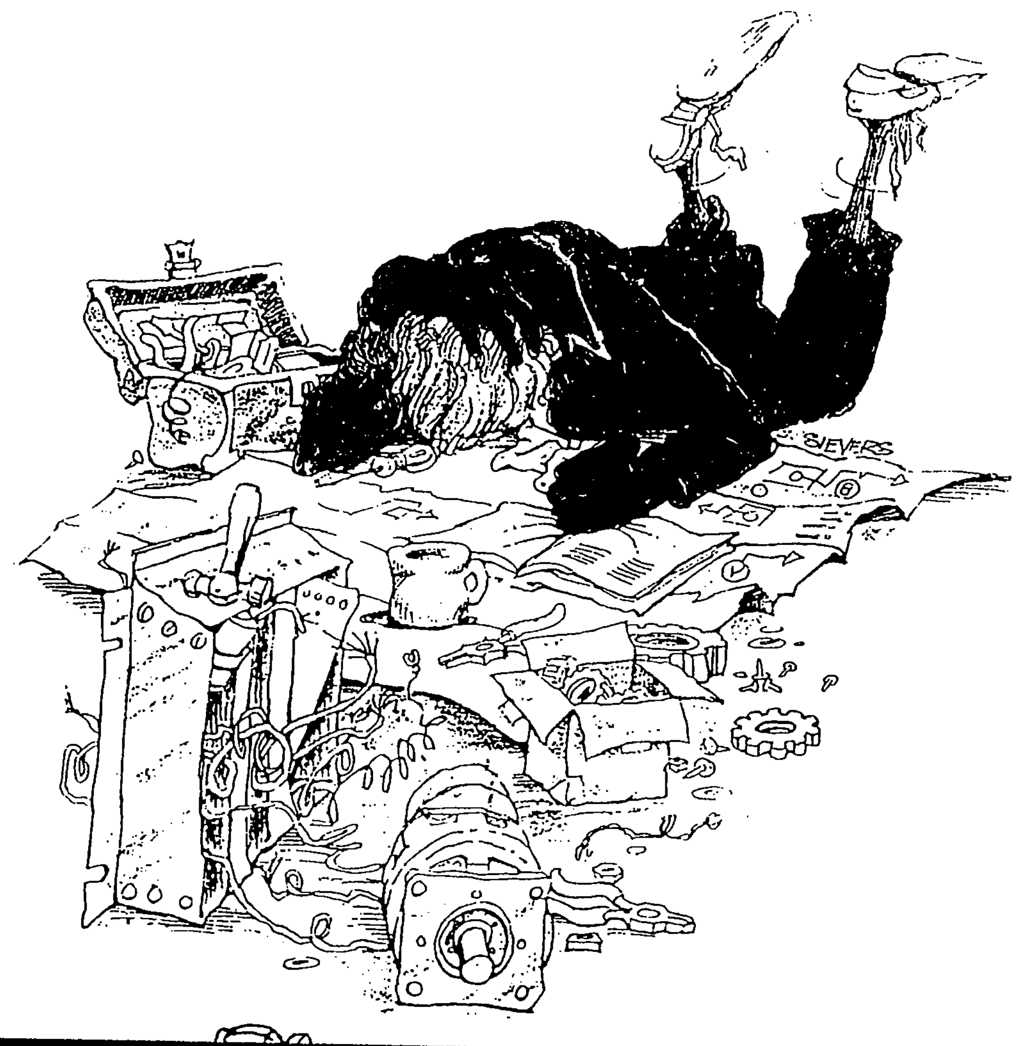
100'00....150'000 Connection Points

Typical Wiring



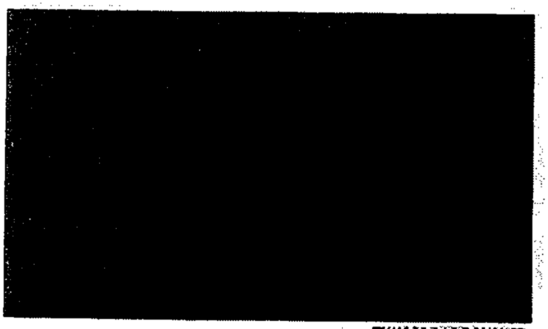
Documentation

Documentation

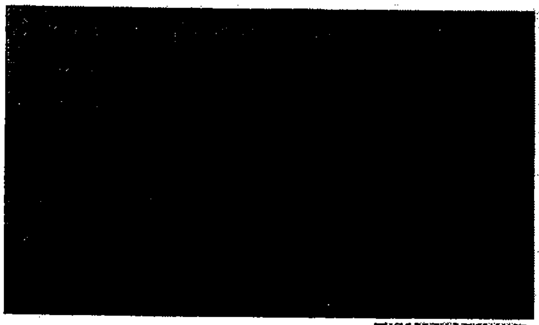


Tasks of the Control and Instrumentation Level

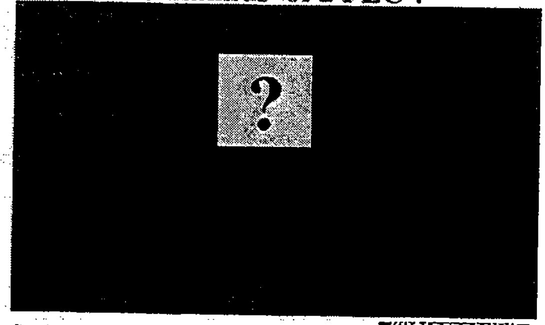
Who can all do this?



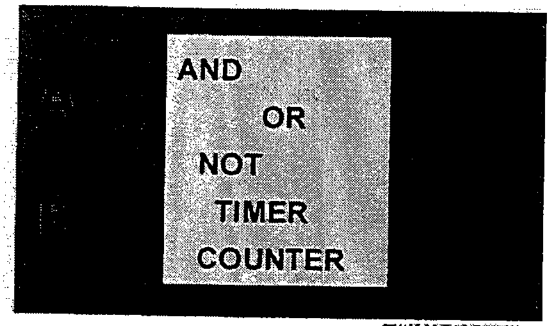
PLC ? What is it ?



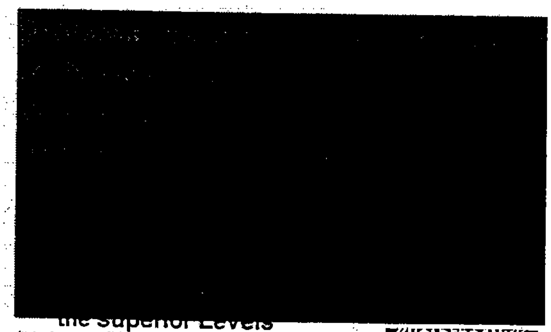
What are the basic functions / commands of a PLC ?



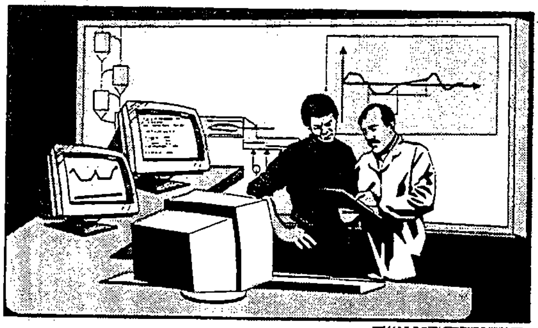
Basic functions of a PLC



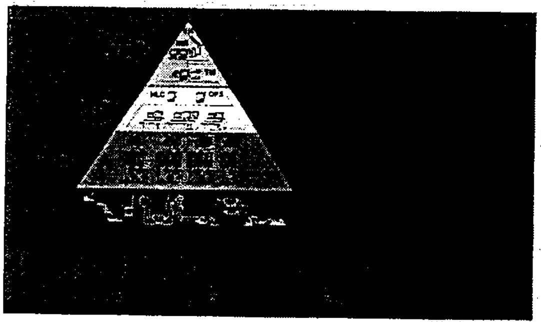
Functions of the Process Control Level



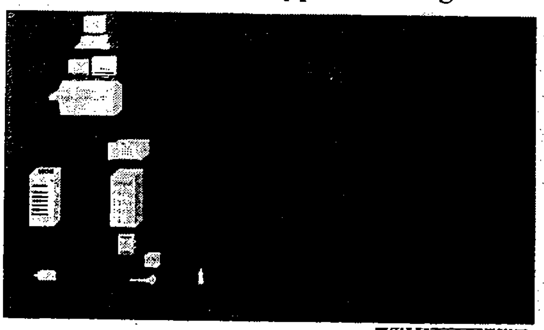
Control Room with Large Screens



Communication



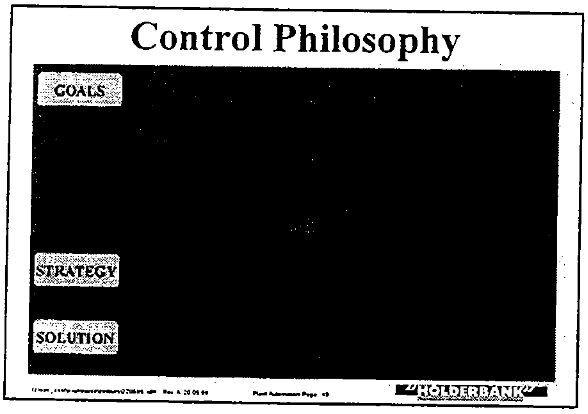
Automation Systems Typical Configuration

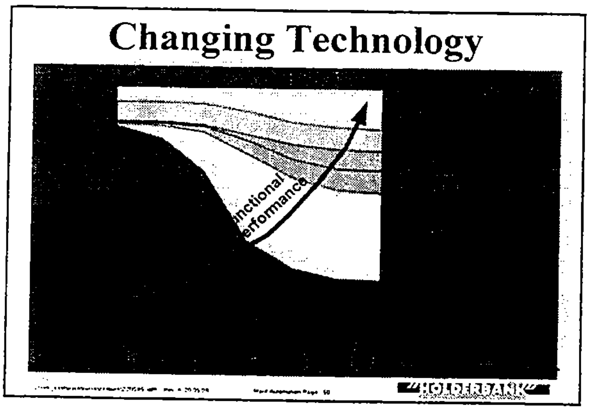


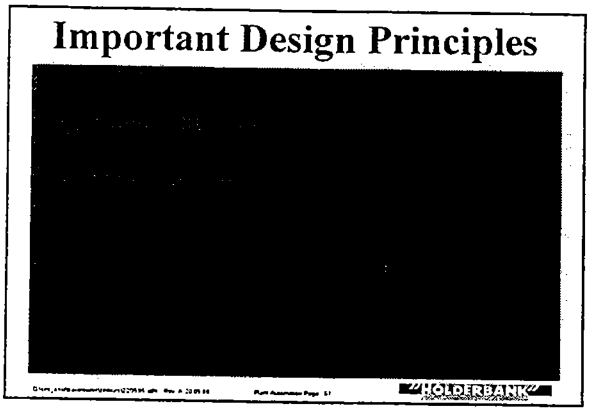
Accepted Standards for Process Control and Production Level

Cement Plant = Long Term Investment

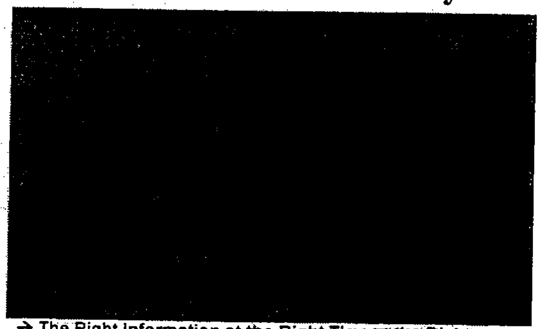
In spite of the high complexity of the demands, the systems must be:


Control Philosophy
GOALS
STRATEGY
SOLUTION
HOLDERBANK

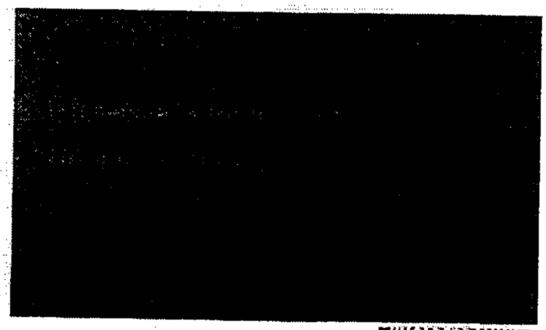

Changing Technology
HOLDERBANK


Important Design Principles
HOLDERBANK

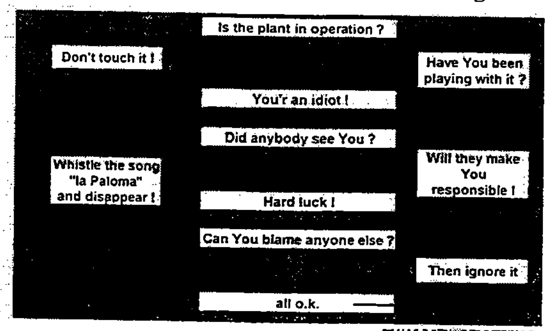
Automation Tendency



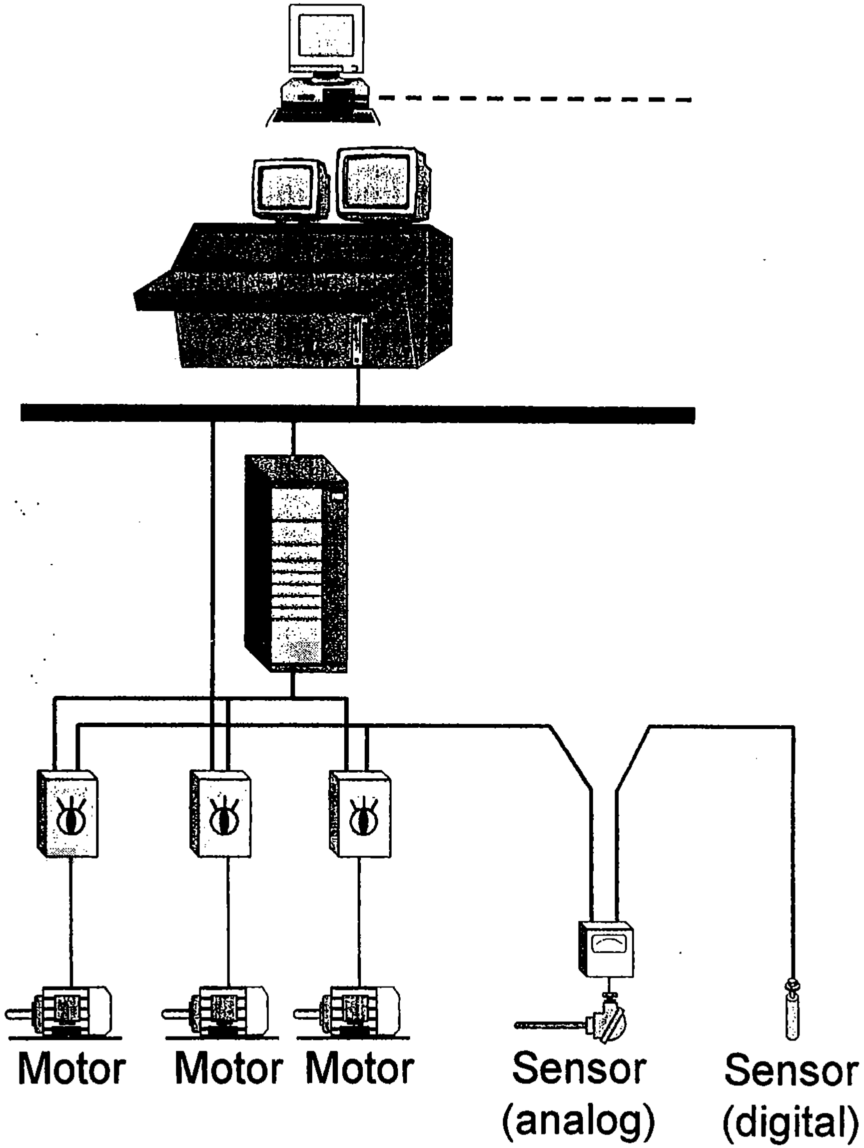
→ The Right Information at the Right Time at the Right Place



Guidelines for Electrical Maintenance Engineers



Automation Systems Future Configuration



← Management Information Network

← Human/Machine Interface
Operator Station
Control System w. Soft PLC

← Network

← LVD Low Voltage Power Distribution

← Cabling, Field Bus, Power Bus

← Distributed Motor Controllers

← Transmitter

← Primary Element